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Assessing Potential Biophysical and Socioeconomic Impacts of Climate Change on Forest-Based Communities: A Methodological Case Study

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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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T.B. Williamson[1], D.T. Price[1], J.L. Beverly[1], P.M. Bothwell,[2] B. Frenkel,[3] J. Park,[3] and M.N. Patriquin[1]

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ABSTRACT

This report presents methods for assessing the potential biophysical and socioeconomic impacts of climate change at scales relevant to forest-based communities. The methods are tested and demonstrated by estimating such impacts for the community of Vanderhoof, British Columbia. First, spatially referenced climate histories and climate scenarios are developed for a 200 km × 200 km study area surrounding Vanderhoof. Second, these climate data are linked to new models and methods for projecting changes in productivity, species, and wildfire risk under conditions of climate change. Third, methods for linking changes in productivity to potential changes in harvest rate and then to potential changes in aggregate household income are developed and applied. Finally, an approach for linking, presenting, and comparing the results from the various methods is presented. This approach takes account of both climate change and parallel socioeconomic changes occurring in a community's external environment and acknowledges the inherent uncertainty in climate and socioeconomic scenarios. The approach is based on the development of multitiered scenario radar maps, which are then compressed into a single radar map providing a concise summary of potential climate impacts on a particular community. The assessment of community vulnerability tends to be specific to a particular location. Nevertheless, the Vanderhoof case study highlights areas where forest-based communities may be uniquely exposed, sensitive, and therefore potentially vulnerable to the impacts of climate change. Climate change may increase fire risk in forests surrounding communities. It is also likely to affect timber supplies (positively, negatively, or both), thereby causing changes in local economic activity and increasing instability and uncertainty. Moreover, these responses may be variable and nonlinear over time. The Vanderhoof experience with the mountain pine beetle (*Dendroctonus ponderosae* Hopkins) shows that climate change has the potential to affect natural capital near other forest-based communities. Reduction of the natural capital asset base supporting any community will ultimately result in negative socioeconomic impacts. Governments (municipal, provincial, and federal) could use the approaches described here to identify locations where natural capital is at greatest risk. This information is needed to develop strategies for either protecting existing natural capital, replacing lost capital, or transforming exposed natural capital to alternative types of assets that are less sensitive to climate change.

RÉSUMÉ

Ce rapport présente différentes méthodes d'évaluation des répercussions biophysiques et socioéconomiques potentielles du changement climatique, à des échelles pertinentes pour les collectivités axées sur les ressources forestières. Les méthodes sont testées et démontrées grâce à l'évaluation des ces répercussions au sein de la collectivité de Vanderhoof, en Colombie-Britannique. Tout d'abord, on élabore des historiques et des scénarios climatiques à référence spatiale pour la région de Vanderhoof, dans une zone d'étude de 200 km sur 200 km. Ensuite, ces données climatiques sont liées à de nouveaux modèles et de nouvelles méthodes de prévision des changements en ce qui concerne la productivité, les espèces et les risques d'incendies de forêt, et ce, selon les conditions établies par le changement climatique. Par la suite, on conçoit et met en application des méthodes pour permettre de faire un lien entre les changements concernant la productivité et les changements potentiels du taux de récolte et du revenu global des ménages. Finalement, on met de l'avant une approche pour lier, présenter et comparer les résultats qui découlent des différentes méthodes. Cette approche tient compte à la fois du changement climatique et des changements socioéconomiques connexes qui ont lieu dans l'environnement externe de la collectivité en plus de reconnaître l'incertitude intrinsèque des scénarios climatiques et socioéconomique. Cette approche tire son fondement de la création de scénarios de cartes radar multiniveaux, qui sont ensuite fusionnées pour ne former qu'une seule carte radar fournissant un résumé concis des répercussions potentielles que peut causer le changement au sein d'une collectivité en particulier. L'évaluation de la vulnérabilité d'une collectivité tend à se rapporter surtout à une région définie. Néanmoins, l'étude de cas de la collectivité de Vanderhoof indique les zones particulièrement sensibles des collectivités axées sur les ressources forestières et donc, présentant une grande vulnérabilité face aux répercussions du changement climatique. Ce phénomène pourrait augmenter le risque d'incendies au sein des forêts qui entourent les collectivités et avoir un impact (positif, négatif ou les deux) sur l'approvisionnement forestier, et ainsi engendrer des changements dans l'économie locale en plus de faire augmenter le degré d'instabilité et d'incertitude. Par ailleurs, au fil du temps, ces réponses pourraient se révéler variables et non linéaires. L'expérience vécue par la collectivité de Vanderhoof en ce qui a trait au dendoctrone du pin ponderosa (*Dendroctonus ponderosae* Hopkins) démontre que le changement climatique peut avoir des répercussions sur le capital naturel d'autres collectivités qui dépendent de la forêt. Une diminution du capital naturel qui soutient une collectivité entraînera inévitablement des répercussions socioéconomiques négatives. Les autorités (municipales, provinciales et fédérales) pourraient utiliser les approches mentionnées dans la présente pour déterminer les endroits où le capital naturel est le plus à risque. Ces renseignements sont essentiels à l'élaboration de stratégies portant sur la protection du capital naturel existant, le remplacement du capital naturel ou encore la transformation du capital naturel à risque en d'autres types de ressources moins vulnérables au changement climatique.

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. Ultimately, vulnerable communities will need to prepare for, and adapt to, these new and changing conditions. The work reported here aims to improve the capacity of forest-based communities to adapt to climate change by developing and demonstrating methodologies for understanding potential exposure and sensitivity (i.e., potential impacts) at community-relevant scales. New methods have recently been developed for estimating potential future climates and for assessing the potential impacts of climate change on forests and communities at higher levels of resolution than has previously been possible. This document reports a case study using these methods for the community of Vanderhoof, located in central British Columbia.

The focus of this report is on assessing the potential impacts on forest-based communities resulting from the impacts of climate change on forests. It is important to recognize that climate change will affect communities in other ways not considered in this document. For example, climate change may have direct consequences for human health and community infrastructure. Also, climate change is likely to affect other industries (notably agriculture and tourism) and other natural resources (such as ground and surface water supplies). Specific model-based approaches for assessing and addressing impacts in these sectors are not considered here.

This is the second of two Canadian Forest Service Information Reports addressing the issue of forest-based communities and climate change. The first report[1] described a vulnerability assessment framework and approach for forest-based communities. This second report provides examples of data sources and methods for detailed technical assessments of potential biophysical and socioeconomic impacts and is the result of a joint initiative between the Canadian Model Forest Network, the McGregor Model Forest (now called Resources North), and the Canadian Forest Service, with the cooperation of the District Municipality of Vanderhoof.

[1]Williamson, T.B.; Price, D.T.; Beverly, J.L.; Bothwell, P.M.; Parkins, J.R.; Patriquin, M.N.; Pearce, C.V.; Stedman, R.C.; Volney, W.J.A. A framework for assessing vulnerability of forest-based communities to climate change. Nat. Resour. Can., Can. For. Serv., North. For. Cent., Edmonton, AB. Inf. Rep. NOR-X-414.

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EXECUTIVE SUMMARY

Human communities will need to adapt to avoid or reduce the impacts of a changing climate. Identification of sources of community vulnerability is an important first step. A framework for assessing the vulnerability of forest-based communities to climate change was presented in a previous report.[1] That report indicated that the estimation of potential impacts (in terms of their nature, timing, and scale) is an important element of vulnerability assessment. The report presented here describes methodologies for assessing potential impacts of climate change at scales that are relevant to forest-based communities. These methodologies have been tested and applied to the community of Vanderhoof, British Columbia. The results from the Vanderhoof case study are used to illustrate how climate change is likely to affect Canada's forest-based communities in general.

This report has the following objectives:

- to report on the application of spatial databases of historical climate and future climate scenarios for the region surrounding Vanderhoof, British Columbia
- to describe the development of new methods for assessing the potential impacts of climate change at community-relevant scales
- to identify the major assumptions and limitations of models for simulating climate impacts at the community scale
- to illustrate how these assessment methods might be applied to other forest-based communities
- to assess how climate change may affect forest-based communities in general, on the basis of results obtained for the Vanderhoof case study

The approaches reported here focus on assessing the potential impacts of climate change on forest resources and the likely consequences for the communities they support. Other ways in which communities might be affected by climate change (e.g., impacts of extreme weather, impacts on health, impacts on local infrastructure) are not assessed, nor are the impacts on nonforestry sectors (e.g., agriculture, tourism) considered. Also, this report does not address the topic of community resources that create "adaptive capacity" (i.e., the ability of the community to adapt to changing conditions).

The Community of Vanderhoof

Vanderhoof is a midsized community (population 4 400) in the central interior of British Columbia. Its main industries are forestry, agriculture, and tourism. Vanderhoof is also a service center (providing government services, health services, education, and retail shopping) for the surrounding region. The forest industry is by far the largest economic sector, accounting for 39% of all jobs and 63% of the community's economic base. The majority of roundwood timber supplied to the mills in Vanderhoof comes from the Vanderhoof Forest District (VFD), where lodgepole pine (*Pinus contorta* Dougl. ex Loud. var. *latifolia* Engelm.) is the dominant tree species, accounting for about 80% of forest cover. Since the mid-1990s the majority of pine trees in the VFD have been attacked by the mountain pine beetle (*Dendroctonus ponderosae* Hopkins) (MPB), which has had significant impacts on the Vanderhoof economy. In 2007, the Vanderhoof economy was strong because of timber supply uplifts that had been imposed to allow for salvage of beetle-killed timber. However, within 10 years, the timber supply will be lower than it was before the beetle outbreak.

The impacts of the MPB are at least partly due to recent changes in climate. In particular, several recent mild winters have allowed expanding beetle populations to survive, whereas previously harsher winters killed them off. However, the beetle outbreak is also partly attributable to other factors—notably fire

[1]Williamson, T.B.; Price, D.T.; Beverly, J.L.; Bothwell, P.M.; Parkins, J.R.; Patriquin, M.N.; Pearce, C.V.; Stedman, R.C.; Volney, W.J.A. 2007. A framework for assessing vulnerability of forest-based communities to climate change. Nat. Resour. Can., Can. For. Serv., North. For. Cent., Edmonton, AB. Inf. Rep. NOR-X-414.

history, land-use development patterns, and the effectiveness of fire suppression. Thus, large-scale impacts of natural phenomena like the MPB outbreak can arise from complex interacting factors, only some of which may be related to climate. In some cases it may be difficult to anticipate all of the precipitating factors and their interactions. Therefore, in addition to the ranges of impacts that can be projected, there is potential for unexpected impacts ("surprises") to occur. In general, projections of future impacts are estimates based on the best available science and should be regularly updated as new information emerges.

Recent and Future Climate Change in the Vanderhoof Study Area

In its Fourth Assessment Report, the Intergovernmental Panel on Climate Change (IPCC)[2] reported that the global mean temperature increased by 0.74 °C between 1906 and 2005. For the same period, an analysis of available data shows that the increase in annual mean temperature for the Vanderhoof study area was about 1.7–1.8 °C. The residents of Vanderhoof have noticed changes in their local climate, reporting a variety of both direct and indirect impacts:

- more abrupt and more severe weather events (winds, storms)
- milder winters
- shorter winter logging seasons
- increased stream flows
- shallower snow packs in the valley
- thinner ice forming on water courses
- new bird species
- overwintering of bird species that used to migrate
- increased winter kill of forage crops because of freeze–thaw cycles

The current study also presents data on historical climate trends and future climate projections for the Vanderhoof study area. Historical temperature and precipitation data for a 200 km × 200 km region centered on Vanderhoof were extracted from a continental-scale data set compiled by the Canadian Forest Service.[3] For the 20th century, precipitation levels were at their lowest during the 1930s, increasing thereafter in all seasons until the mid-1960s. Since then, spring, summer, and fall average precipitation has changed little from the 30-year means, although winter precipitation may have declined since the 1970s. Monthly mean daily minimum temperatures in the Vanderhoof study area increased steadily between 1900 and 2000 (Figure ES.1), whereas there has been no corresponding trend for monthly mean daily maximum temperature. The general warming trend has been driven mainly by higher nighttime temperatures (when most daily minimums occur), which implies an overall decrease in diurnal temperature range.

The scenarios of future climate for this study were developed from simulation results from three general circulation models (GCMs, also referred to as global climate models): the Canadian Second-Generation Coupled Global Climate Model (CGCM2), the Hadley Centre Third-Generation Coupled Model (HadCM3), and the Commonwealth Scientific and Industrial Research Organization (CSIRO) Mark 2 model (CSIRO Mk2). For each model, simulation results were obtained for two IPCC greenhouse gas (GHG) emissions scenarios. The relatively pessimistic A2 scenario, taken from the *Special Report on Emissions Scenarios*,[4] assumes a rate of increase in GHG emissions comparable to the rate of increase in the 1990s. In the more optimistic B2 scenario, societies are more socially and environmentally conscious, with slower population growth, lower energy intensity, and less reliance on fossil fuels, which leads to much lower growth in GHGs. The key difference is in the assumed increase in atmospheric carbon dioxide (CO_2) concentration by 2100: to about 820 parts per million by volume (ppm) for the A2 scenario and to about 605 ppm for the B2 scenario (the present-day [2007] level being about 385 ppm

[2]Solomon, S.; Qin, D.; Manning, M.; Marquis, M.; Averyt, K.; Tignor, M.M.B.; Miller, H.L., Jr.; Chen, Z., editors. 2007. Climate change 2007: the physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge Univ. Press, Cambridge, UK. Also available at http://www.ipcc.ch/ipccreports/ar4-wg1.htm.
[3]McKenney, D.W.; Pedlar, J.H.; Papadopal, P.; Hutchinson, M.F. 2006. The development of 1901–2000 historical monthly climate models for Canada and the United States. Agric. For. Meteorol. 138:69–81.
[4]Nakicenovic, N.; Swart, R., editors. 2000. Special report on emissions scenarios. A special report of Working Group II of the Intergovernmental Panel on Climate Change. Cambridge Univ. Press, Cambridge, UK. Also available at http://www.ipcc.ch/ipccreports/sres/emission/index.htm.

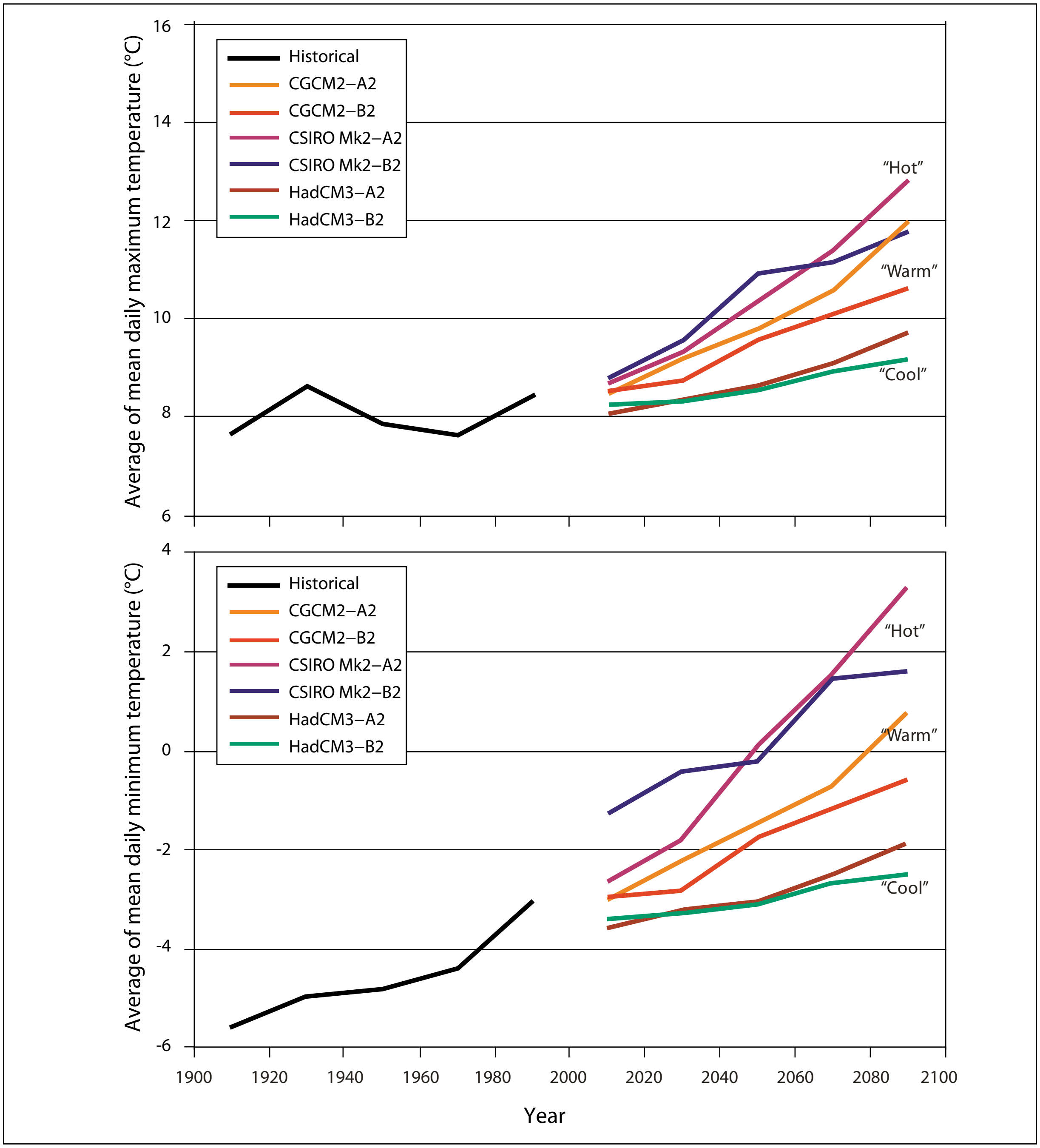


Figure ES.1. **Historical and possible future trends in annual mean daily minimum and maximum temperatures in the Vanderhoof region, 1901–2100.** Mean daily minimum and maximum temperatures were calculated annually for each weather station in the area; these station means were then averaged to generate the overall mean for each year. Each data point is averaged from 20 years of monthly values and spatially averaged over 350 grid cells (covering the 200-km rectangle surrounding Vanderhoof). Hence the lines show only the general trends and do not show a lot of year-to-year variation. Historical data (up to 2000) have been interpolated from available climate station records. Future projections (from 2001 onwards) were taken from six different general circulation model simulations. CGCM2 = Canadian Second-Generation Coupled Global Climate Model; CSIRO Mk2 = Commonwealth Scientific and Industrial Research Organization Mark 2 model; HadCM3 = Hadley Centre Third-Generation Coupled Model; A2 = scenario with a regionalized global economy in which the rate of increase in greenhouse gas emissions is comparable to the rate of increase in the 1990s; B2 = scenario with a regionalized global economy in which societies are more socially and environmentally conscious than in scenario A2, with slower population growth, lower energy intensity, and less reliance on fossil fuels, leading to a much lower rate of growth in greenhouse gas emissions.

and the preindustrial [around 1860] level being about 280 ppm). The combination of three GCMs and two emission scenarios therefore yielded six "GCM scenarios" of future climate for the Vanderhoof study area.

The various scenarios suggest that, by 2100, mean daily minimum temperatures could increase by 1.5 ºC–6.0 ºC, whereas mean daily maximum temperatures could increase 1.0 ºC–4.0 ºC (Figure ES.1). Projected trends in precipitation are much less definitive, with the results from the CGCM2 and HadCM3 models overlapping and showing no clear increase over the long term. In contrast, the CSIRO Mk2 model projects increases in mean annual precipitation of about 100 mm by 2100, which represents an increase of approximately 20% over the mean for 1961–1990.

Potential Impacts of Climate Change on Forests in the Study Area

Impacts on Harvest Levels through MPB Outbreak

The 20th century warming trend has contributed to the ongoing MPB outbreak, which has had a major impact on forests in the Vanderhoof study area. As a result, annual allowable cuts (AACs) of timber have been temporarily increased to allow for salvage of beetle-killed timber. These uplifts will continue for a few years, but major reductions in annual harvests are anticipated sometime before 2020. Before the beetle outbreak, the AAC in the VFD was about 2 million m^3. It was increased to 3.8 million m^3 in 2002 and then to 6.5 million m^3 in 2004. However, on the basis of a 2004 analysis by the British Columbia Ministry of Forests and Range (BCMOFR),[5] the projected harvest for the VFD after the beetle outbreak subsides is between 1.0 million and 1.6 million m^3 yr^{-1}.

Impacts on Forest Ecosystems

The anticipated changes in long-term forest harvest presented above do not take account of the long-term effects of climate change and increasing atmospheric CO_2 concentration on forest productivity, nor do they account for the possible effects of a warmer and drier climate on the frequency and intensity of wildfires and other natural disturbances. To investigate these effects, the GCM climate scenarios were used to drive computer models of forest composition and productivity and of wildfire occurrence within the Vanderhoof study area.

Growth, mortality, competition, and succession of forest vegetation were simulated using a dynamic vegetation model called the Canadian Integrated Biosphere Simulator (Can-IBIS). With inputs of soil and historical climate data for the Vanderhoof region, mapped at 10-km resolution, Can-IBIS was reasonably successful in simulating present-day characteristics of local vegetation (notably forest composition and productivity), but it tended to overestimate standing volume. When driven by three different scenarios of future climate (CGCM2 and CSIRO Mk2, both forced by the A2 emissions scenario, and HadCM3, forced by the B2 emissions scenario), Can-IBIS predicted a range of plausible changes in vegetation composition and productivity for the year 2100. Simulated forest productivity generally increased, consistent with generally warmer conditions, adequate moisture, and increasing atmospheric CO_2 concentration. The sensitivity of primary productivity to rising CO_2 was consistent with recent observations. With relatively small increases in temperature and no appreciable increase in annual precipitation (HadCM3–B2 scenario), vegetation composition was predicted to change relatively little from the conifer-dominated forest in the area today (productivity increases by 23% by 2050). With the greater warming predicted by the CGCM2–A2 scenario, productivity increases by 34% by 2050, (evidently in response to higher temperatures) and there is a small shift toward greater hardwood composition and a boreal type forest. The CSIRO Mk2–A2 scenario projected a much greater shift in species composition (a significant increase in boreal and temperate hardwoods and a decrease in conifers by 2100) and an increase in overall forest productivity by about 34% by 2050.

Impacts on Wildfire

An analysis of wildfire regimes in the Vanderhoof study area was based on results from the BURN-P3 model,[6] carried out at

[5]Pedersen, L. 2004. Prince George Timber Suply Area: rationale for annual allowable cut (AAC) determination. B.C. Minist. For., Victoria, BC.
[6]Parisien, M.A.; Kafka, V.G.; Hirsch, K.G.; Todd, J.B.; Lavoie, S.G.; Maczek, P.D. 2005. Mapping wildfire susceptibility with the BURN-P3 simulation model. Nat. Resour. Can., Can. For. Serv., North. For. Cent., Edmonton, AB. Inf. Rep. NOR-X-405.

100-m resolution. In addition to daily weather data, BURN-P3 requires high-resolution data on fuel types. Because of these detailed data requirements, the potential impacts of climate change on wildfire susceptibility were assessed using only one climate scenario. The CGCM2–B2 climate scenario proved to be the "worst-case" projection for the 2050s (i.e., lowest mean annual precipitation) and was therefore selected for the fire analysis. The four panels in Figure ES.2 show the resulting maps of fire susceptibility for the Vanderhoof study area, comparing the pre-MPB fire situation with current (i.e., about 2004) conditions and with two scenarios of fire susceptibility in the future (about 2050). The top left panel represents the baseline, i.e., historical climate conditions before the MPB outbreak. The top right panel shows current fire susceptibility, taking account of the impacts of the MPB on fuels in the study area. In this case, the needles of dead and dying pine trees are still on the trees ("red state"), which increases fire susceptibility relative to baseline. The BURN-P3 simulations estimate a 76% increase in areas with moderate fire susceptibility, a 169% increase in areas with high susceptibility, and a 184% increase in areas with extreme fire susceptibility relative to pre-MPB conditions.

The bottom panels of Figure ES.2 assume that by the period 2041–2060, the fuels in the study area will be in the low-flammability "gray state" (when all needles will have dropped from dead pine trees). The bottom left scenario assumes fire weather conditions that are unchanged from baseline (i.e., the region's climate is unchanged). For this scenario, BURN-P3 projects a 19% increase in the proportion of the study area in the low-susceptibility state and decreases in the areas of moderate, high, and extreme susceptibility classes of 70%, 96%, and 100%, respectively. The bottom right panel assumes similar fuel conditions but assumes that climate change will occur according to the CGCM2–B2 scenario, for which BURN-P3 projects a 96%, 60%, and 59% increase in areas of moderate, high, and extreme fire susceptibility classes (relative to baseline). Thus, the changes in fire weather associated with the CGCM2–B2 scenario are projected to more than offset the general reductions in flammability as the pine forest shifts from the red to the gray state.

Potential Impacts of Climate Change on the Economy of the Prince George Timber Supply Area

Models for estimating the economic impacts of climate change specific to the Vanderhoof study area are not available. Instead, the economic impacts of climate change for a larger study area, the Prince George Timber Supply Area (PGTSA), were simulated with an existing computable general equilibrium(CGE) model.[7] This simulation necessitated first estimating the impacts of climate change on future harvest potential. Projections of future harvest developed for this area by the BCMOFR (and based primarily on MBP effects) were combined with forest productivity as simulated by Can-IBIS for the Vanderhoof study area to generate four projections of harvest potential in 2055. These projections, which consider the impacts of both the MPB outbreak and future climate change,[8] were based on a variety of assumptions about the ultimate magnitude of the MPB outbreak (best and worst cases) and the future effects of climate change on forest productivity in the PGTSA (also best and worst cases). The baseline annual harvest for the PGTSA (i.e., before the MPB outbreak and before accounting for any possible impacts of climate change) was assumed to be 9.4 million m^3 (i.e., the same as the AAC). The four projections for annual harvest rates in the year 2055 were as follows: (1) best-case MPB and best case climate, 10.8 million m^3; (2) worst-case MPB and best-case climate, 9.9 million m^3; (3) best-case MPB and worst-case climate, 9 million m^3; and (4) worst-case MPB and worst-case climate, 8.3 million m^3.

These four projections of harvest potential were incorporated into a CGE model previously developed for the PGTSA, to assess potential impacts on the region's economy up to the year

[7]Patriquin, M.; Heckbert. S.; Nickerson, C.; Spence, M.; White, B. 2005. Regional economic implications of the mountain pine beetle infestation in the northern interior forest region of British Columbia. Nat. Resour. Can., Can. For. Serv., Pac. For. Cent., Victoria, BC. Mountain Pine Beetle Initiative Work. Pap. 2005-3.
[8]This analysis is based on a number of simplifying assumptions (as described in the main report) and is relevant only as a way of providing broad-based and strongly qualified indicators of potential impacts. The results presented here should not be considered as projections of future timber supply.

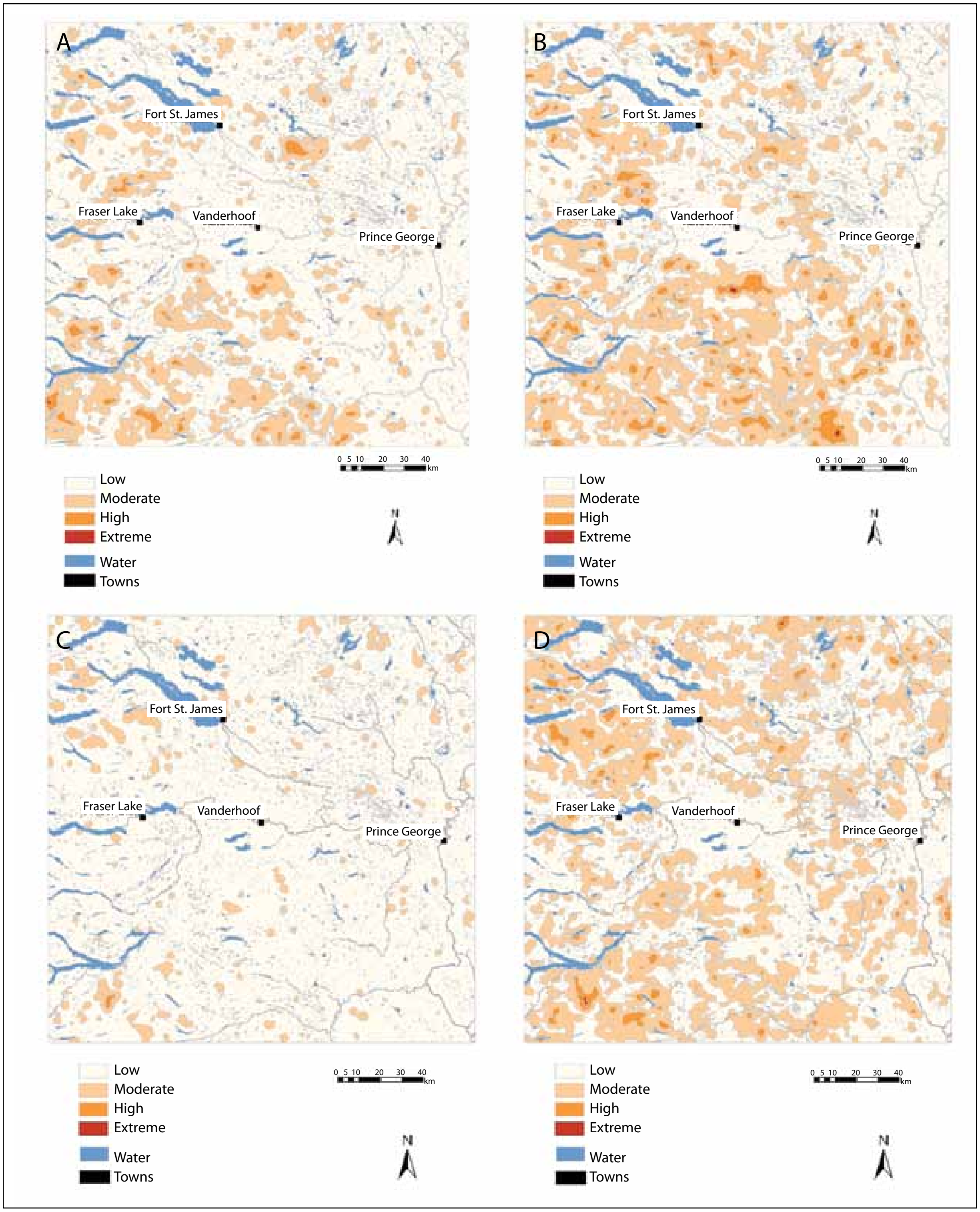


Figure ES.2. Fires susceptibility classification for the Vanderhoof study area under various past, present and future conditions. A. Baseline (pre-beetle) scenario. B. Current fuel conditions. C. Future fuels (no climate change). D. Future fuels (with climate change).

2055. The analysis assumed a direct one-to-one relation between changes in harvest rate and changes in forest industry exports (e.g., harvest was projected to increase about 10.6% under the best-case MPB and best-case climate projection and therefore exports in 2055 were estimated to increase by 10.6% relative to the baseline). The analysis also assumed that the structure of the economy would not change during the analysis period (i.e., capital stocks were assumed to be fixed).

Projections of the future economic impacts of climate change will also vary depending on assumptions about how the economy will adjust to changes in forest sector exports. If wage rates are assumed to be fixed, then all of the adjustment will occur through changes in employment levels (i.e., some unemployment may occur). Conversely, if complete flexibility of wages is assumed, then all adjustments will occur through wage levels, and the economy will remain fully employed irrespective of changes in export levels. These two assumptions represent the extremes of what will likely occur in reality, but they are required (as "closure rules") to enable the general equilibrium model to generate a solution.

The combination of four projections of forest industry exports and two rules for model closure (fixed and flexible wages) resulted in eight projections of the impact of climate change on household incomes for the PGTSA by 2055. Under the most optimistic set of assumptions, total annual household income would increase from about $1.60 billion in 2000 to almost $1.70 billion by 2055. Under the most pessimistic set of assumptions, household incomes would decrease to slightly less than $1.55 billion (a result that does not include losses that might occur because of significant increases in wildfire). In the short term (i.e., up to 2010), the MPB would have a positive impact, but the medium-term (2025) consequences of the outbreak would be negative. In the longer term (2055), climate change is projected to result in increased forest productivity, leading to increases in harvest potential, which may accelerate economic recovery to some extent. Conversely, increases in area lost to wildfires could offset or even reverse these gains. The net impact will depend on the ultimate extent of beetle and wildfire damage, the climate scenario (if any) that most closely anticipates reality, and the extent to which the PGTSA economy adjusts to external economic shocks.

As noted above, this analysis covers the PGTSA as a whole, since it was not feasible to conduct a comparable economic analysis for the smaller economy of the Vanderhoof study area. However, it can reasonably be inferred that positive economic impacts are less likely for Vanderhoof and, conversely, that negative impacts are more likely (and will probably be more significant), mainly because the impacts of the MPB outbreak on timber supply are more severe in the VFD study area than in the larger PGTSA (where species other than pines are more common). Even with anticipated productivity gains from climate change, it is unlikely that harvests in the VFD will recover to pre-MPB levels before 2055.

Another qualification regarding the quantitative economic modeling is that it considers only those impacts that might occur as a result of effects on timber supplies and harvest potential, whereas the ultimate impacts of climate change on Vanderhoof will result from the combined effects of many factors, including climate-induced changes in global markets for forest products, global socioeconomic trends (e.g., economic growth, energy consumption, global market integration), impacts on other resource sectors, and local biophysical impacts (e.g., impacts on water resources, changes in wildfire, changes in forest-species composition and productivity). One way of assessing the possible combined impacts of multiple factors on the Vanderhoof economy is through qualitative scenario analysis.

Community Impact Scenarios for Vanderhoof

The combined impacts of global and climate change on Vanderhoof are summarized in the form of four community impact scenarios (numbered I through IV in Figure ES.3). These scenarios represent combined impacts at community-relevant scales, while addressing the uncertainty inherent in future projections. The four scenarios are constituted from two subgroups of scenarios (Figure ES.3). Given that climate change is a global phenomenon and given that

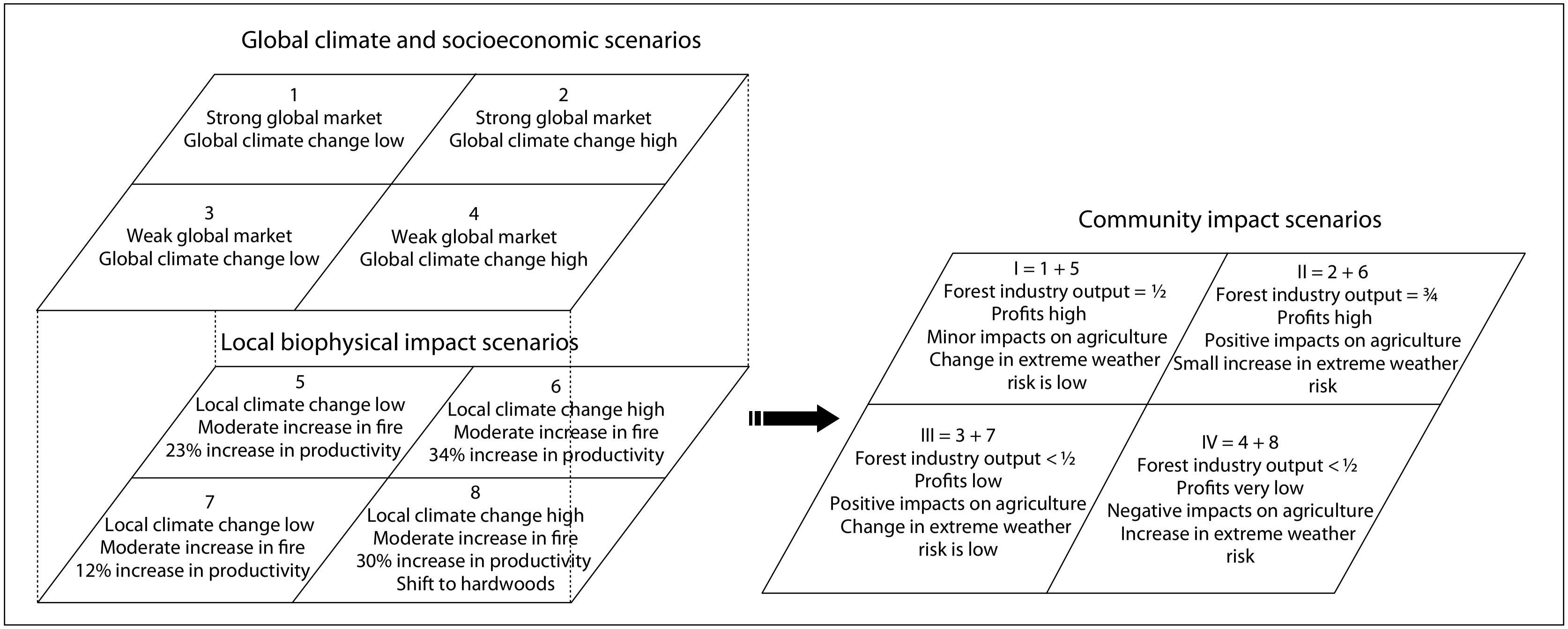


Figure ES.3. **Example framework, using the Vanderhoof case study, for integrating global climate, socioeconomic, and local biophysical impact scenarios for the purposes of developing community impact scenarios.** The top level of the box on the left provides four scenarios with different combinations of global climate change and global market change. The bottom level of the box on the left provides four scenarios of local biophysical impacts under different assumptions regarding local climate change and sensitivity. The chart on the right compresses the two layers and summarizes community-level impacts. For example, quadrant I on the right is based on the assumed conditions and impact scenarios associated with quadrants 1 and 5 on the left.

the Vanderhoof economy is closely tied to the global economy, the global socioeconomic future will have important implications for Vanderhoof. Scenarios 1–4 in Figure ES.3 portray different global futures defined in terms of the global climate and the global economy. However, as noted previously, climate change will also have important implications for forest resources in the Vanderhoof study area. Scenarios 5–8 in Figure ES.3 portray different scenarios of the local biophysical impacts defined in terms of alternative projections of local climate change and forest response.

Community Impact Scenario I

Socioeconomic Outlook

Under community impact scenario I, there is a significant increase in the demand for goods and services provided by the Vanderhoof economy through a combination of a high rate of growth in the global economy and the local presence of globally competitive firms. At the same time, countries across the globe have managed to control GHG emissions, so there is less atmospheric forcing, and the rate of climate change is slower than it would have been if nothing had been done. Vanderhoof becomes a highly attractive location for investment because of its combination of a highly skilled local labor force, natural amenities, available natural resources, strong local leadership, and favorable institutional environment. The forest industry continues to be important, but the economy becomes more diversified over time. Global population is projected to reach between 10 billion and 15 billion by 2100, and world economic wealth is increasing. Thus, demand for agricultural products and wilderness tourism opportunities may be increasing.

Climate Outlook

Changes in climate in the Vanderhoof area are relatively minor. Average daily temperature increases by about 0.5 °C by the year 2050 and by about 1.75 °C by 2100 (relative to the year 2000). Average annual precipitation increases marginally (from 550 mm in 2000) by 2050 and to about 575 mm by 2100.

Forest Ecosystem Impacts

The HadCM3–B2 climate and emissions projection was used for the ecosystem analysis for this scenario. The moderate changes in climate are insufficient to trigger large changes in the dominant forest vegetation in the Vanderhoof area by 2100. By 2050, forest productivity increases by up to 23% because of longer growing seasons and CO_2 fertilization.

Wildfire Susceptibility

The CGCM2–B2 climate and emissions projection was used for the fire analysis for this scenario. In the short term, immediately after beetle-caused tree mortality, there is a significant increase in wildfire susceptibility, but susceptibility declines again once the dead needles drop from the trees. In the longer term, the CGCM2–B2 scenario represents the worst-case climate scenario from a fire standpoint. Under this scenario there is moderate warming but little increase in precipitation, and the area becomes progressively drier, at least until 2050. The result is some increase in fire susceptibility relative to the period before the beetle outbreak and a significant increase relative to the state after the needles have fallen. There is an 82%–118% increase in the proportion of critical fire weather days in the Vanderhoof area and increases of 60% and 59%, respectively, in the area in the high and extreme fire susceptibility classes. There is a moderate increase in the length of the fire season, and the average number of escaped fires (i.e., fires > 20 ha) in the Vanderhoof study area increases from three to five per year.

Forestry-Related Impacts

In the short term (over the next 15 years), the harvest is subject to significant volatility because of initial uplifts for salvage purposes, followed by major fall-downs, which leads to some volatility in the local economy. In the medium term, the lower rate of climate change with community impact scenario I means that climate-related increases in forest productivity are about 23%. This results in smaller harvests, lower production, and fewer exports than might have been the case if climate change had been more pronounced (as in community impact scenario II). The allowable harvest in the VFD and forest industry exports are slightly more than half what they were in the year 2000 because of the combined effects of MPB, productivity changes, and wildfire. The forest industry is profitable because of growing demand (and increases in real prices), and it remains an important industry. However, production after the beetle declines does not recover to prebeetle levels. The contribution of the forest industry relative to that of other industrial sectors in Vanderhoof is declining.

Other Impacts

The impacts of climate change on agricultural production, tourism opportunity, fisheries, and water resources are relatively minor. Relative changes in the risk of extreme weather events are small. Population growth and increased global income may increase the demand for agricultural products and wilderness tourism opportunities.

Community Impact Scenario II

Socioeconomic Outlook

The global economy is strong, but the world's nations have not taken the initiative to reduce GHG emissions, and global climate change is therefore significant. Under this scenario, commodity-driven economic growth is emphasized, and environmental protection (at the global scale) is not a high priority. The Vanderhoof economy is strong and growing but remains commodity-based; however, it is somewhat more diverse as a result of new value-added businesses that have been attracted because of the business-friendly climate. A moderately high rate of global climate change has resulted in an increase in global timber supply, but global demand for forest products has increased in direct proportion to this increase in supply, and real prices for these products are flat. Global population is projected to reach between 10 billion and 15 billion by 2100, and world economic wealth is increasing. Thus, demand for agricultural products and wilderness tourism opportunities may be increasing. The Vanderhoof economy fully recovers from the downturns of the mid-2020s, which were caused by the fall-down in local harvest (due to the MPB event) and associated decreases in production in the forest industry. The main sources of growth are industries unrelated to forestry, such as services, agriculture, and tourism, although wood may be used for bioenergy. Under this scenario, the vulnerability of the Vanderhoof economy to climate change (in terms of economic exposure) is moderately low because of the strength of the global economy and the potential for increased productivity in the agriculture and forestry sectors.

Climate Outlook

The change in climate in the Vanderhoof area over the next 100 years is significant. Average daily temperature, calculated annually, increases by about 2.5 °C by the year 2050 and by about 4.5 °C by 2100 (both relative to 2000). Average annual precipitation increases from about 550 mm (in 2000) to about 600 mm by 2050 and to 650 mm by 2100.

Forest Ecosystem Impacts

The CGCM2–A2 climate and emissions projection was used for the ecosystem analysis for this scenario. Projected changes to the forest in the Vanderhoof study area are relatively limited, with shifts in species composition to more drought-tolerant conifers (pine [*Pinus* spp.], Rocky Mountain Douglas-fir [*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco]) and increases in hardwood content. Forest productivity increases by up to 34% by 2050 because of longer growing seasons and CO_2 fertilization.

Wildfire Susceptibility

The CGCM2–A2 climate and emissions projection was used for the fire analysis for this scenario. By 2050, there is a 31%–111% increase in the proportion of critical fire weather days during the fire season. The total area with high or extreme fire susceptibility increases to some extent but is still smaller than under community impact scenario I. The potential for even more significant increases in fire risk is negated by the higher precipitation by 2050 in the CGCM2–A2 scenario relative to the CGCM2–B2 scenario.[9] The amount of global warming is higher than in community impact scenario I. The fire season becomes longer than what is expected under scenario I, but conditions are not as dry. Thus, the average number of escaped fires (i.e., > 20 ha) in the study area increases from three to four per year.

Forestry-Related Impacts

The worst-case beetle scenario occurs, and harvests in the Vanderhoof study area reach the maximum fall-down around 2020. After 2020,

[9]For the period around 2050, the CGCM2 scenarios are drier (projecting lower precipitation) than the HadCM3 and CSIRO2 models.

however, harvesting opportunities increase because of climate-induced increases in the productivity of the remaining forest. However, the costs for delivered wood may also increase as a result of reduced opportunities for winter harvest. The supply of forest products from other countries into global markets increases significantly, but growth in demand keeps pace, and real prices remain flat. Thus, the local forest industry remains profitable, and forest industry exports in 2050 are approximately 75% of 2000 levels (after MPB, productivity, and wildfire effects on local supply are taken into account). Increased global timber supply caused by global climate change is a source of vulnerability for forestry producers in the Vanderhoof area, a problem that is offset to some degree by increased productivity of the region's forests.

Other Impacts

The Vanderhoof agriculture sector benefits from increased food demand (due to increased global population and increased world income), better growing conditions (a longer growing season, more precipitation, and CO_2 fertilization), and the ability to adapt quickly to changing environmental conditions. There is a reduction in forest aesthetics during periods of transition from one forest type to another. Water temperatures increase, which reduces salmon and trout (*Oncorhynchus* spp.) populations. Winters are shorter and milder, and summers are longer. The snowpack is reduced, spring runoff occurs earlier, and summer flow rates are reduced. There is a general reduction in old-growth forest and in the population levels of species with large home ranges and those that prefer relatively pristine forest settings (such as caribou (*Rangifer tarandus caribou* (Gmelin, 1788)) and grizzly bear (*Ursus ursus* Linnaeus, 1758)); conversely, however, ungulate populations may increase. Precipitation may increase through the more frequent occurrence of intense storm events, leading to the possibility of increased risk of flooding. There may be an increased risk of other forms of extreme weather (e.g., droughts, heat waves, and severe storm activity). The potential for change in the landscape surrounding Vanderhoof is a source of vulnerability for tourism operators in the area.

Community Impact Scenario III

Socioeconomic Outlook

In the short term, the local economy experiences some economic volatility because of MPB-related uplifts and fall-downs. In the medium- to long-term, community impact scenario III describes a future in which the extent of climate change is moderately low, but growth in global markets is weak and global market conditions are unfavorable to the Vanderhoof economy. Under this scenario, global commodity demand is depressed because of measures taken to reduce energy use and emissions. Alternative energy technology is being adopted, but Vanderhoof has not kept pace with other regions in terms of implementing the new technology and attracting regional investment. As a result, economic diversity is relatively low and profitability marginal. Despite relatively high local adaptive capacity, the region has been ineffective in reducing barriers to adaptation, which has in turn constrained the implementation of appropriate adaptive responses. Climate change is not a source of vulnerability to the local economy, but general economic conditions may be.

Climate Outlook

Changes in climate in the Vanderhoof area are relatively minor. The average daily temperature increases by about 0.5 °C by the year 2050 and by about 1.75 °C by 2100 (both relative to 2000). Average annual precipitation increases marginally by 2050 and to approximately 575 mm (from 550 mm in 2000) by 2100.

Forest Ecosystem Impacts

The HadCM3–B2 climate and emissions projection was used for the ecosystem analysis for this scenario; however, forests were assumed to be less sensitive than under community impact scenario I. The moderate changes in climate are insufficient to trigger large changes in the dominant forest vegetation in the Vanderhoof area by 2100. Forest productivity increases by a relatively modest 12% under this scenario. (Note that this 12% value is assumed, not derived. The HadCM3–B2 scenario actually projects a 23%

increase in productivity by 2050, but the value of the productivity increase has been scaled down for the purposes of this community impact scenario to reflect the assumption of lower forest sensitivity.)

Wildfire Susceptibility

The CGCM2–B2 climate and emissions projection was used for the fire analysis for this scenario. In the short term, immediately after beetle-caused tree mortality, there is a significant increase in wildfire susceptibility, but susceptibility declines again once the dead needles drop from the trees. In the longer term, the CGCM2–B2 scenario represents the worst-case climate projection from a fire standpoint. There is moderate warming but little increase in precipitation, and the area becomes slightly drier. The result is some increase in fire susceptibility relative to the period before the beetle outbreak, and a significant increase relative to conditions after the needles have fallen. There is an 82%–118% increase in the proportion of critical fire weather days in the Vanderhoof area, and increases of 60% and 59%, respectively, in the proportion of the study area in the high and extreme fire susceptibility classes. The length of the fire season increases, and the average number of escaped fires (i.e., > 20 ha) doubles from three to six per year.

Forestry-Related Impacts

In the short term (over the next 15 years), local harvest rates are highly variable because of the effects of the MPB. This leads to some volatility in the local economy. In the medium term, the lower rate of climate change means that climate-related increases in forest productivity do not materialize. This results in smaller harvests, lower production, and fewer exports than might have been the case if climate change were more pronounced. In terms of global markets for forest products, growth in demand is flat, but anticipated increases in the global timber supply due to climate change do not materialize. As a result, real (i.e., inflation-adjusted) prices for forest products remain flat. The forest industry remains important, but production and exports are less than 50% of 2000 levels, mainly because of a combination of reduced timber supply (due to MPB, productivity effects, and wildfire) and flat prices.

Other Impacts

The impacts of climate change on agriculture, tourism, fisheries, water resources, and outdoor recreation opportunities are relatively minor. Agriculture productivity benefits somewhat from climate change in this scenario. Changes in the risk of extreme weather events are small. Thus, climate change is not a significant source of vulnerability in terms of environmental impacts on the landscape surrounding Vanderhoof.

Community Impact Scenario IV

Socioeconomic Outlook

Community impact scenario IV describes a future in which the extent of climate change is moderately high (the A2 emissions scenario), and global markets are not only weak, but also unfavorable to the Vanderhoof economy. Because of the socioeconomic component of this scenario, the Vanderhoof economy would be under some pressure even without changes in the climate. The significant climate change reinforces and magnifies the economic and social challenges faced by the community by contributing to an increased global supply of agriculture and forest products at a time when global demand is relatively weak. Under this scenario, investment and technological advancement in other regions of the world are outpacing those in Vanderhoof, and, despite the community's market focus, profitability and economic diversity are low. Investment and technology remain focused on commodity markets, but unfavorable global market conditions are depressing the local economy, creating unemployment and low investment. Pressure grows for the community to deal with immediate concerns relating to issues other than climate change. The community's resources are fully engaged in dealing with these issues, and its ability to adapt to new and unanticipated challenges, including those caused by climate change, may be low.

Climate Outlook

The change in climate in the Vanderhoof area over the next 100 years is significant. Average annual daily temperature increases by about 2.5 °C by the year 2050 and by about 4.5 °C by 2100. Average annual precipitation increases from about 550 mm (in 2000) to about 600 mm by 2050 and 650 mm by 2100.

Forest Ecosystem Impacts

The CSIRO Mk2–A2 climate and emissions projection was used for the ecosystem analysis for this scenario. The forest in the Vanderhoof study area starts showing evidence of a shift from conifer domination to a far higher deciduous component. Conifer productivity increases, but hardwoods account for a larger portion of the forest inventory. Forest productivity increases by 30% for this scenario. Note that this 30% value is assumed, not derived. The CSIRO Mk2–A2 scenario actually projects a 34% increase in productivity by 2050, but the value of the productivity increase has been scaled down for the purposes of this community impact scenario to reflect the assumption of lower forest sensitivity.

Wildfire Susceptibility

The CSIRO Mk2–A2 climate and emissions projection was also used for the fire analysis for this scenario. This climate and emissions projection causes the greatest temperature increases and the highest increase in precipitation of all of the projections. There is a 31%–111% increase in the proportion of critical fire weather days during the fire season. The percentage of the area in the high and extreme fire weather classes increases to some extent, but not as much as in community impact scenario III. The length of the fire season increases, and the average number of escaped fires (i.e., > 20 ha) increases from three to five per year.

Forestry-Related Impacts

The worst-case beetle scenario occurs, and harvests in the Vanderhoof study area reach the maximum fall-down around 2020. After 2020, however, harvesting opportunities increase (because of climate-induced increases in the productivity of the remaining forest). Local increases in harvest opportunity are offset to some degree by higher costs of delivered wood, because of reduced opportunity for winter harvest. There is also a significant increase in the timber supply in global forestry markets from other countries, and global demand for forest products is flat. Thus, Canadian producers face declines in real (i.e., inflation-adjusted) prices. The local forest industry becomes a marginal supplier and is the first to shut down during cyclical economic downturns. A persistent period of low prices (and higher costs for delivered wood) leads to some mill closures. Under this community impact scenario, climate change combined with flat markets and high costs represents a source of vulnerability to local producers of forest products. Forest industry output and exports are less than 50% of 2000 levels, mainly as a result of market pressures.

Other Impacts

Growing conditions and length of the growing season for agricultural production improve, but these changes are offset by increases in the variability of the weather. The world agricultural economy has become regionalized (through a failure to liberalize trade), and export opportunities for Canadian producers are low. There is a reduction in forest aesthetics during periods of transition from one forest type to another, which has a major negative impact on the local tourism industry. Water temperatures increase, which reduces salmon and trout populations. Winters are shorter and milder, and summers are longer. The snowpack is reduced, spring runoff occurs earlier, and summer flow rates are reduced. There is a general reduction in old-growth forest and in the population levels of wildlife species with large home ranges and those that prefer relatively pristine forest settings (such as caribou and grizzly bear); conversely, however, ungulate populations may increase. Precipitation may increase through the more frequent occurrence of intense precipitation events, leading to the possibility of an increase in the risk of flooding. There may also be a significant increase in the frequency of other forms of extreme weather (e.g., droughts, heat waves, or severe storm activity). Increased exposure of local residents to changes in the landscape and increased risks of extreme weather are sources of vulnerability under this scenario.

Conclusions

The Vanderhoof example illustrates that climate change has already been, and will likely continue to be, a significant factor leading to changes in local timber supply (and the local economy) over relatively short time frames. In general, forest-based communities should not assume that future timber supplies will continue to support their forest industries at current levels. However, each community's experience with climate change will be unique. Impacts will be specific to particular locations, as will be the most appropriate course of action required to adapt to those impacts. The assessment of a particular community's vulnerability will require analysis that takes account of these location-specific factors.

The Vanderhoof case study highlights some general aspects where forest-based communities may be exposed and sensitive—and therefore potentially vulnerable—to the impacts of climate change. For example, climate change may affect several interacting forest-disturbance agents simultaneously. Climate warming in the late 20th century has contributed to the unprecedented MPB outbreak in Vanderhoof and the surrounding area. The resulting large-scale tree mortality has greatly increased fuel loadings, causing increases in susceptibility to wildfires (although this susceptibility is expected to decline significantly once the dead needles fall). In the long term, continued climate warming will produce more frequent periods of high and extreme fire weather, so wildfire activity is projected to increase. Thus, the local effects of climate warming on natural disturbances are complex and dynamic.

An important impact of climate change on forest-based communities will be the potential for increases in wildfire risk in communities located close to flammable forests. Increases in the frequency and intensity of wildfire in fire-prone areas will result in increased risks to property and infrastructure, increases in the need for evacuation, potential health impacts from smoke, and increases in the frequency of forest closures.

Climate change may also affect timber supply through multiple interacting factors. On one hand, longer growing seasons and CO_2 fertilization may lead to increased biological productivity, particularly in regions where soil factors (i.e., water and nutrients) are not limiting. On the other hand, as previously noted, increased disturbances (including droughts and disease, as well as insects and fire) are almost certain to increase losses of standing timber. The net effects on AAC will depend on the magnitude of possible gains in productivity balanced against increased disturbance losses.

Climate change is expected to contribute to instability in wood supply and increased instability in the local economy. Vanderhoof is currently experiencing an economic boom (through the salvage of beetle-killed timber), but this will end within a decade, once the salvage is complete. Forest-based communities that are small and undiversified are especially exposed to such fluctuations in wood supply.

Climate change may result in higher costs for delivered wood. The most cost-effective season for harvesting is winter, when the ground is frozen. However, climate change is resulting in warmer and shorter winters, and winter harvest opportunities are decreasing (and will probably continue to decrease in the future). As a result, more all-weather roads will be needed, and delivered-wood costs will be generally higher.

Climate change is also likely to affect forest-based communities through structural changes in forest products markets. Some economists have projected that global timber supply will increase, but with much of the economic benefit accruing to producers in countries such as Chile and Brazil, where tree growth rates are inherently higher and labor costs typically much lower than in Canada. Economic diversification and strategic investments by governments and firms to promote and develop nontraditional products and new market niches will be needed to reduce the vulnerability of Canadian forest-based communities to these global market changes.

Community sustainability depends on local endowments of resources and assets, including human and natural capital, financial capital, infrastructure, and technology. A community's access to assets and the benefits they bring is affected by institutions and local leadership. In general, climate change will contribute to increased risk and uncertainty for forest resources and for the assets of firms and households in forest-based communities. Sudden changes in local wood supply will have important implications for a forest-based community, especially if it cannot be replaced by other types of assets. This analysis shows that projected changes in climate have the potential to significantly and suddenly decrease natural capital in the vicinity of communities like Vanderhoof. Provincial and municipal governments and forest managers will also face increased risks to organizational objectives, which indicates a need for risk management strategies at all levels. Canada's forest-based communities should investigate their individual vulnerability to the impacts of climate change and assess their ability to adapt to the anticipated changes. Some general adaptation options include protecting natural capital at risk, building new assets to replace those that will be lost as a result of climate change, and converting high-risk forms of natural capital to other forms of capital before the natural capital is lost or damaged.

INTRODUCTION

Forest-based communities in Canada are potentially vulnerable to climate change (Davidson et al. 2003; Standing Senate Committee on Agriculture and Forestry 2003). However, the degree and nature of community vulnerability varies significantly from place to place. One reason for these differences is the wide variation in the relation between forest-based communities and surrounding climate-sensitive forests. A second reason is that climate change is not expected to occur uniformly across Canada. A third reason is that communities may vary in terms of their capacity to adapt to climate change. Diversity in the nature of the relations between communities and forests, combined with spatial variability in climate change and potential forest impacts, means that there will be differences in the *exposure* and *sensitivity* of individual forest-based communities to climate change impacts; measurement of adaptive capacity, the third factor determining vulnerability[1] to climate change, will be addressed in later reports. Assessing the potential impacts of climate change on any particular forest-based community requires methods that account for location and other community-specific factors influencing exposure and sensitivity. To date, the estimation of climate change impacts at community-relevant scales has not been possible. The impacts of climate change have been assessed at global (e.g., Solomon et al. 2007), and national (e.g., Lemmen et al. 2008) scales. Historically, higher resolution analysis (e.g., at community-relevant scales) was limited by a lack of higher resolution climate scenarios and by a lack of higher resolution integrated assessment methodologies for estimating potential biophysical and socioeconomic impacts under different climate scenarios. This report presents methods for addressing these gaps and illustrates their application in a case study undertaken for the community of Vanderhoof in central British Columbia.

Improving our capacity to assess the potential impacts of climate change on communities is important because such information should provide a guide for *adaptation* at community-relevant scales. Efficient and effective investment in adaptation has the potential to reduce, in turn, the potential net impacts of climate change on communities. In summary, climate change will have impacts on communities, and these impacts will be higher without adaptation than with adaptation. However, adaptation at community-relevant scales will be difficult to undertake unless and until there is a better understanding of potential impacts at community-relevant scales.

This report has the following objectives:

- to report on the application of spatial databases of historical climate and future climate scenarios for the region surrounding Vanderhoof, British Columbia
- to describe the development of new methods for assessing the potential impacts of climate change at community-relevant scales
- to identify the major assumptions and limitations of models for simulating climate impacts at the community scale
- to illustrate how these assessment methods might be applied to other forest-based communities
- to assess how climate change may affect forest-based communities in general, on the basis of results obtained for the Vanderhoof case study

The assessment of climate impacts at community-relevant scales is a new and evolving area of research. The data and methods described in this report are "first approximations." They are intended to provide estimates of potential impacts at scales not previously investigated. The modeling approaches are, in many respects, incomplete and oversimplified, and the results should be interpreted with caution. Nonetheless, it is hoped that these results will stimulate further development of the approaches described here, leading to more detailed and more reliable projections and assessments in the future.

[1]Vulnerability is a function of the exposure of a system to climate and climate change, its sensitivity to change, and its adaptive capacity (McCarthy et al. 2001).

Analytical Framework

This report presents several approaches for estimating the potential impacts of climate change on forests and the consequent potential socioeconomic impacts on forest-based communities. The methods and approaches described here can be used in support of a broader approach to the assessment of vulnerability (as described by Williamson et al. 2007). Figure 1 shows the general assessment framework. The following components of the framework are described and illustrated in this document: community overview (step 2), local climate (step 3), climate scenarios (step 4), ecosystem effects and wildfire risk (steps 5 and 6), socioeconomic scenarios (step 7), and potential impacts on the local economy (steps 8 and 9). These aspects generally determine a community's exposure and sensitivity to climate and climate change. Methodologies for assessing and describing adaptive capacity (steps 10 to 13) are not considered in this document and will be addressed in a later report.

Study Scope

This report focuses primarily on methods for assessing the potential impacts of climate change on forest resources and the likely consequences for forest-based communities. Communities may be vulnerable to climate change in other ways (see Figure 2) that are not considered in this report in any detailed way. For example, climate change may affect human health and community infrastructure and may result in increased risk from other extreme weather events (e.g., drought, floods, and storms). Furthermore, this study does not consider the possible specific effects of a changing climate on other economic sectors in the Vanderhoof region, notably agriculture and tourism (although some general implications of climate change for these sectors will be presented).

Figure 1 includes a box labeled "plan and implement adaptation options." The reason for undertaking a vulnerability assessment is to allow communities to begin evaluating the need for adaptation and identifying specific adaptation options. The identification and implementation of adaptation measures is best undertaken by the communities themselves. A scientifically based vulnerability assessment may inform adaptation, but it does not and cannot substitute for local expertise and decision-making about how best to adapt. Thus, specific recommendations about adaptation are not included in this study.

Case Study Approach

This report describes a number of methodologies that might be used at community levels and illustrates their application for one particular community. This case study approach is justified because it provides a practical way of illustrating the application of multiple methodologies for the assessment of impacts at community scales.

The case study approach is also justified on methodological grounds. Qualitative case study research is commonly used in a range of disciplines, including law, medicine, education, anthropology, psychology, sociology, management sciences, political science, and economics (Merriam 1988; Yin 2003). The case study approach is applicable to specific types of research problems, particularly in situations where the research problem is holistic and multiple sources of information are required for the analysis (Merriam 1988; Yin 2003), the analysis and results are qualitative in nature (even though some supporting components are quantitative) (Merriam 1988), it is difficult to systematically manipulate and/or control the variables of interest (i.e., formal experimental approaches to examine cause and effect are not feasible), description and explanation (as opposed to empirical prediction) are required for some phenonena, the issue being investigated involves a large number of interacting factors in one situational context (as opposed to a few variables measured over a range of contexts) (Merriam 1988), the analysis concerns an overarching issue that is affecting a bounded system (Smith 1978), the context of the analysis and the phenomena being studied are intertwined (Yin 2003), and a specific case study analysis can be interpreted more broadly or generalized to other situations (Merriam 1988).

The research problem of interest for this study was the need to understand how and why forest-based communities are vulnerable to climate change. The purpose was not

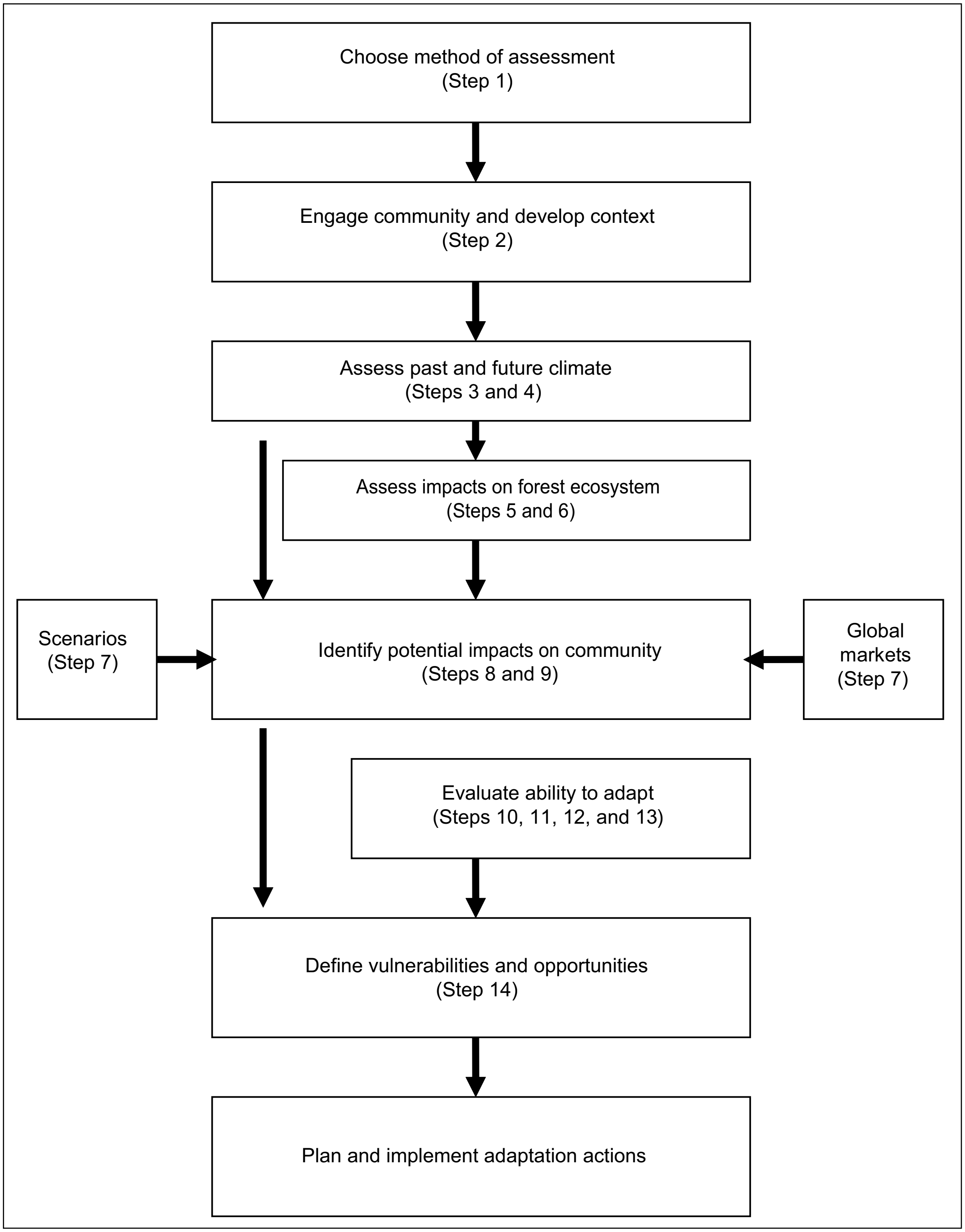


Figure 1. **Conceptual model for vulnerability assessment of forest-based communities.** Source: Williamson et al. (2007); reprinted with permission.

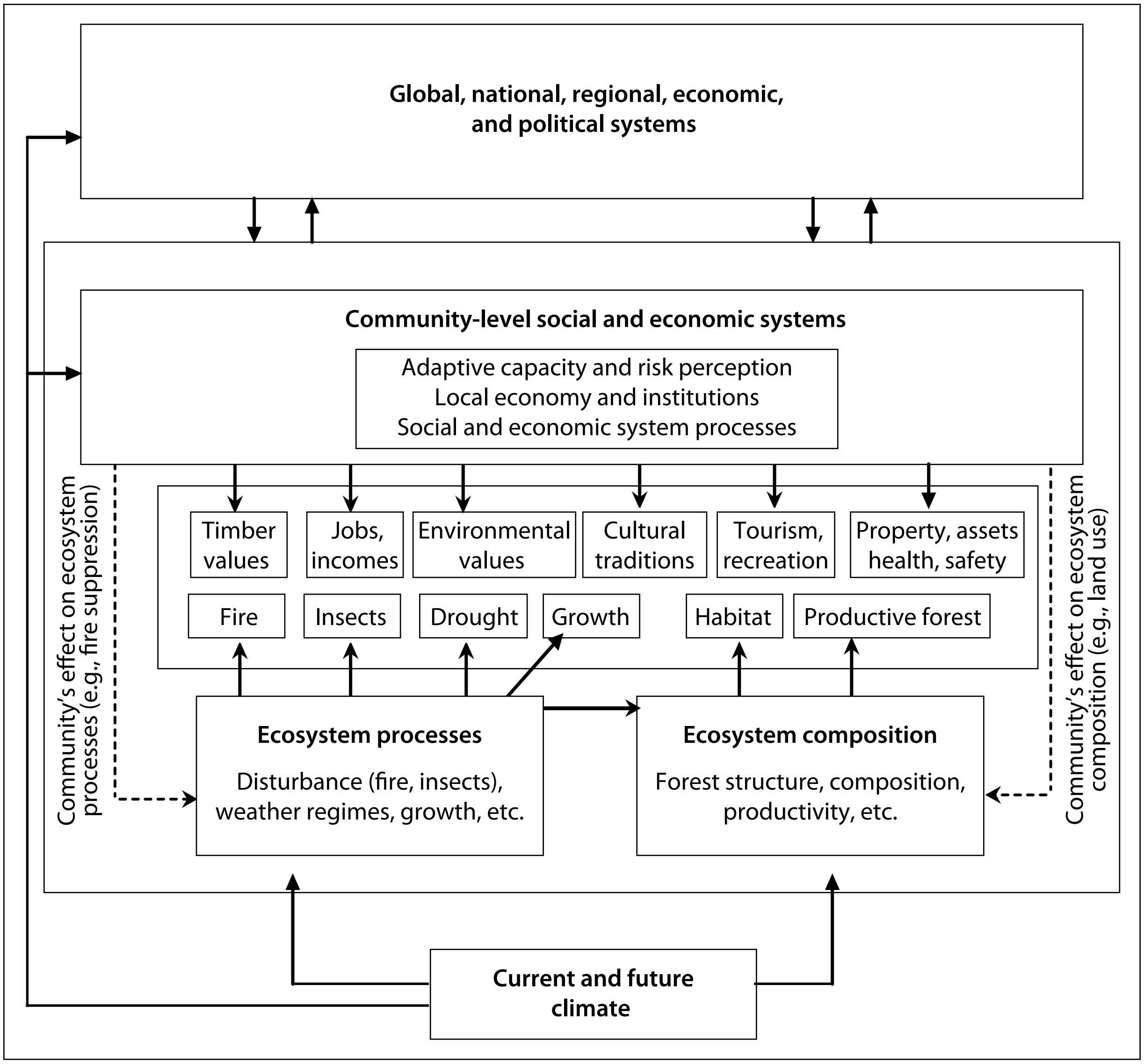


Figure 2. **Exposure pathways to climate change for forest-based communities.** Source: Williamson et al. (2007); reprinted with permission.

to quantitatively predict vulnerability or to rank a community according to its measured vulnerability. Rather, the research problem was holistic, multidisciplinary, and qualitative in nature. Vulnerability assessment considers local climatology, potential biophysical impacts, socioeconomic futures, potential socioeconomic impacts, risk, and the adaptive capacity of dependent human systems in a particular situational context (in this case, the bounded systems of a forest-based community). Thus, the study of community vulnerability combines a variety of data that are both quantitative and qualitative in nature. Moreover, the research problem requires consideration of the results and analysis of all individual components or elements in the context of the bounded systems of a forest-based community. Thus, given the nature of analyzing a community's vulnerability to climate change, case study research is the most suitable methodological approach for beginning to understand the ways in which climate change may manifest in communities.

Description of the Study Area

This study examines the impacts of climate and climate change on forests in a predetermined area around Vanderhoof, British Columbia. In consultation with the mayor and local council, it was decided that the study area should be an area 200 km × 200 km, centered on the town of Vanderhoof. The boundaries of the study area are shown in Figure 3.

Physical Description

Located within the Montane Cordillera Ecozone (Ecological Stratification Working Group 1995), the study area is divided diagonally by the boundary between two ecoregions (Figure 4) (ecoregions are described in Appendix 1). Areas to the southwest are within the Fraser Plateau ecoregion and areas to northeast are within the Fraser Basin ecoregion.

Figure 4 also shows the biogeoclimatic zones that occur in the study area. The majority of the study area (88%) is located within the Sub-Boreal Spruce biogeoclimatic zone. This zone has a continental climate characterized by temperature extremes with summers that are warm but moist. Smaller portions of the study area fall within three other zones: the Sub-Boreal Pine–Spruce, the Engelmann Spruce–Subalpine Fir, and the Alpine Tundra zones. The Sub-Boreal Pine–Spruce zone has cool, dry summers, due to its relatively high elevations and the influence of a rain shadow associated with the coastal mountain range. The higher elevations of the study area fall within the Engelmann Spruce–Subalpine Fir zone, where winters are long and cold and summers are short and cool. Elevation across the study area ranges from 552 to 1 998 m above sea level (Figure 5).

The area immediately surrounding Vanderhoof consists of private and agricultural land, and most of the remaining land in the study area is crown-owned forested land. The forested land base surrounding Vanderhoof is within the Vanderhoof Forest District (VFD), which is in turn part of the Prince George Timber Supply Area (PGTSA) (Figure 6).

The VFD includes approximately 1.37 million ha of land. The low, rolling landscape is crossed by numerous river systems and low-lying wetlands. Major river systems include the Nechako, Stuart, Sutherland, Blackwater, Chilako, and Entiako rivers. Each of these river systems supports spawning runs of salmon (*Oncorhynchus* spp.), steelhead (*Oncorhynchus mykiss*), and other fish species. The Blackwater and Entiako rivers are both listed as world-class sportfishing rivers. The Nechako River is also home to British Columbia's largest freshwater fish species, the Nechako white sturgeon (*Acipenser transmontanus* Richardson).

The forests in the VFD consist primarily of lodgepole pine (*Pinus contorta* Dougl. ex Loud. var. *latifolia* Engelm.) and spruce (*Picea* spp.), with patches of aspen (*Populus* spp.), fir (*Abies* spp.), tamarack (*Larix* spp.), and birch (*Betula* spp.). Lodgepole pine is the dominant tree species in the district, at about 82% of overall forest cover; it provides the majority of commercial timber stands in the area. Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Fanco var. *menziesii*) is sparsely scattered across the VFD, primarily toward the southeast. Higher elevations have occasional small stands of Englemann spruce (*Picea engelmanii* Parry ex Engelm.) and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.). As described in more detail below, the forest stands in the Vanderhoof area are a product of frequent large-scale forest fires. Hence, the relatively few forest stands older than 250 years are composed of Douglas-fir (which is more fire-tolerant than lodgepole pine or spruce) and subalpine fir growing on moister, north-facing slopes.

The area supports an abundance of wildlife. Common ungulate species include mule deer (*Odocoileus hemionus* (Rafinesque, 1817)) and moose (*Alces alces* (Linnaeus, 1758)). Grizzly bear (*Ursus ursus* Linnaeus, 1758), elk (*Cervus elaphus* Linnaeus, 1758), cougar (*Puma concolor* (Linnaeus, 1771)), and woodland caribou (*Rangifer tarandus caribou* (Gmelin, 1788)) occur, but their populations are sparse, declining, or restricted to particular locations within the VFD. Populations of black bear (*Ursus americanus* Pallas, 1780), wolf (*Canus* spp.), coyote (*Canis latrans* Say, 1823), and lynx (*Lynx canadensis* Kerr, 1792) are healthy, as are populations of smaller mammals such as porcupine (*Erethizontidae dorsatum* (Linnaeus, 1758)), skunk (*Mephitis mephitis* (Schreber, 1776)), beaver (*Castor canadensis* (Kuhl, 1820)), marten (*Martes americana* (Turton, 1806)), fisher (*Martes pennanti* (Erxleben, 1777)), fox (*Vulpes vulpes* (Linnaeus, 1758)), squirrel (*Spermophilus parryii* (Richardson, 1825)), and rabbits (*Leporidae* spp.). Bird species that can be seen in the area include white pelican (*Pelecanus erythrorhynchos* Gmelin.), white swan (*Cygnus buccinator* Richardson), bald eagle (*Haliaeetus leucocephalus* Linnaeus), great gray owl (*Strix nebulosa* Forster), various hawks (*Leucopternis* spp.), and a variety of migratory species such as songbirds and woodpeckers. The area is on a flyway for migrating Canada geese and other waterfowl (BC Ministry of Agriculture and Lands 1997).

Soils and landforms in the area around Vanderhoof are the result of glacial processes. Fertile soils occur in the valley bottoms, which support the local agriculture industry, whereas upland sites and poorly drained sites remain mostly forested. There is an abundance of water bodies ranging from small swamps to large lakes, notably Stuart, Tachick, Nulki, Tatuk, and Sinkut lakes. There are also several low-lying mountain ranges, primarily in the southern portion of the forest district. Before settlement, the forest ecosystems in the VFD experienced frequent wildfires, ranging from small spot fires to large-scale burns (BC Ministry of Agriculture and Lands 1997). These natural wildfires occurred on a fire cycle of 100 to 150 years, forming the majority of the forest stands existing in the district today (Pedersen 2004). Land clearing during the period 1920 to 1950 also contributed to significant levels of fire activity. In more recent years, reduction of widespread land-clearing practices combined with fire-suppression activities has reduced the frequency of fire in the area, which has in turn resulted in a high proportion of even-aged pine stands in mature age classes.

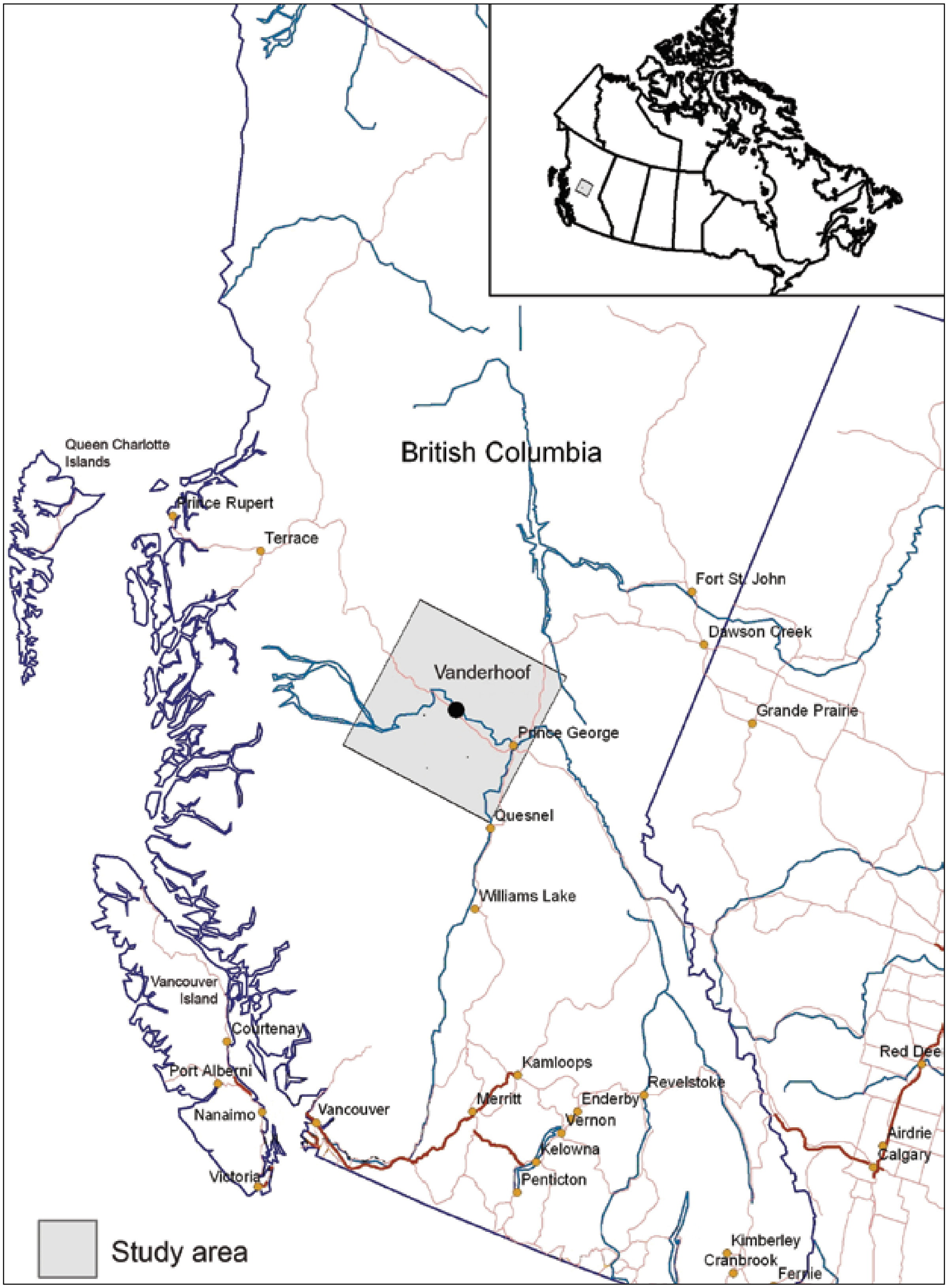


Figure 3. Vanderhoof study area.

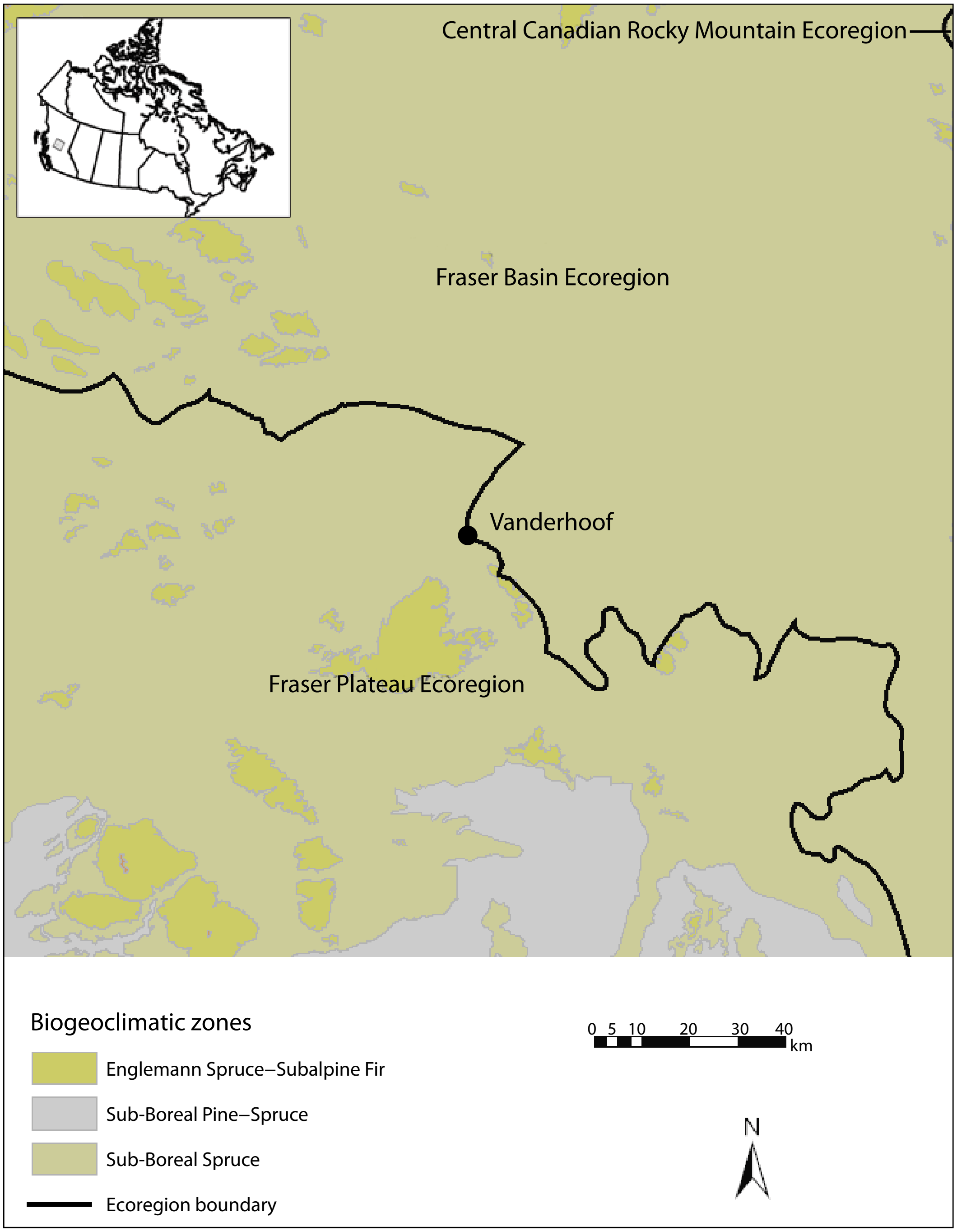


Figure 4. Ecoregions and biogeoclimatic zones within the study area.

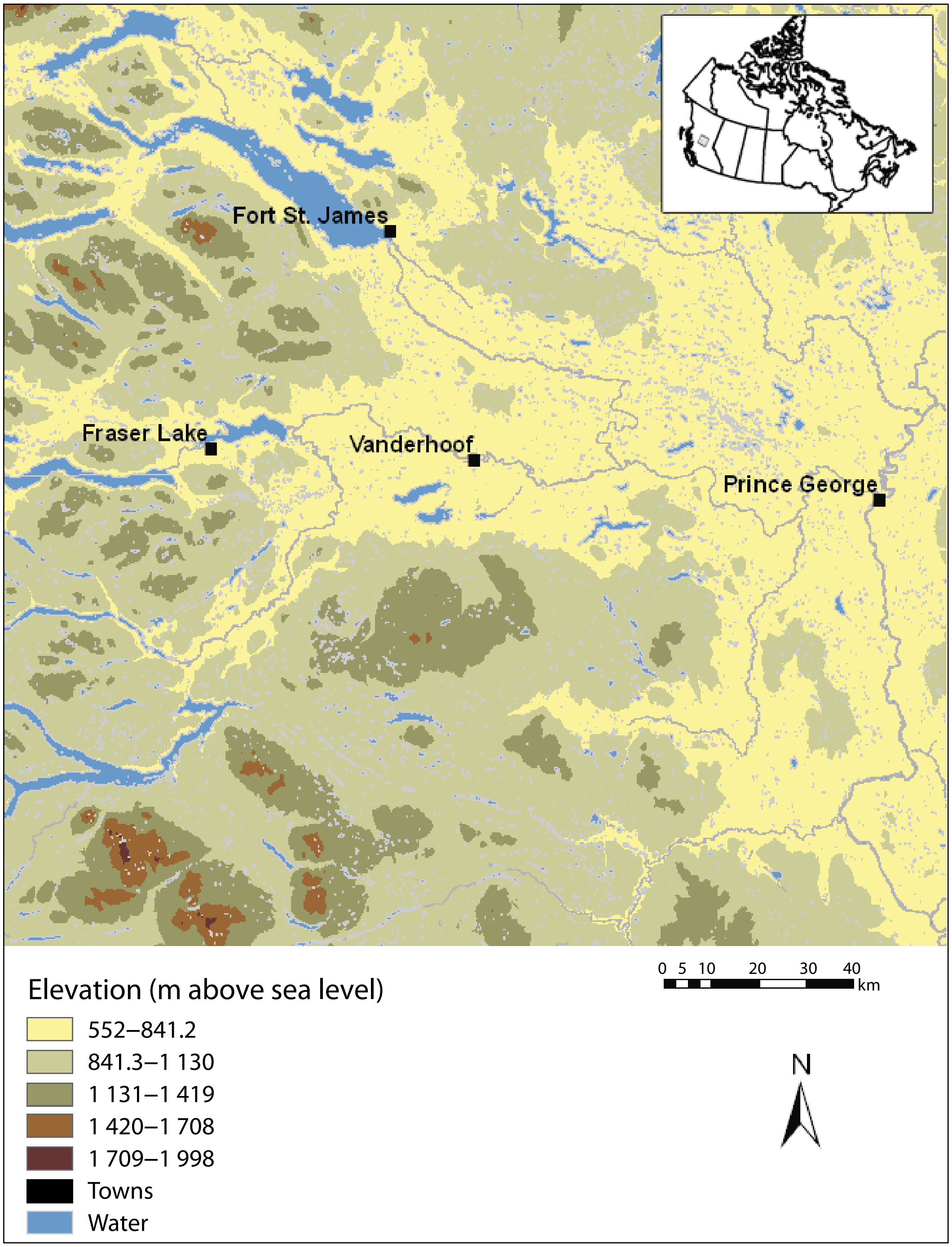


Figure 5. **Elevation within the study area.**

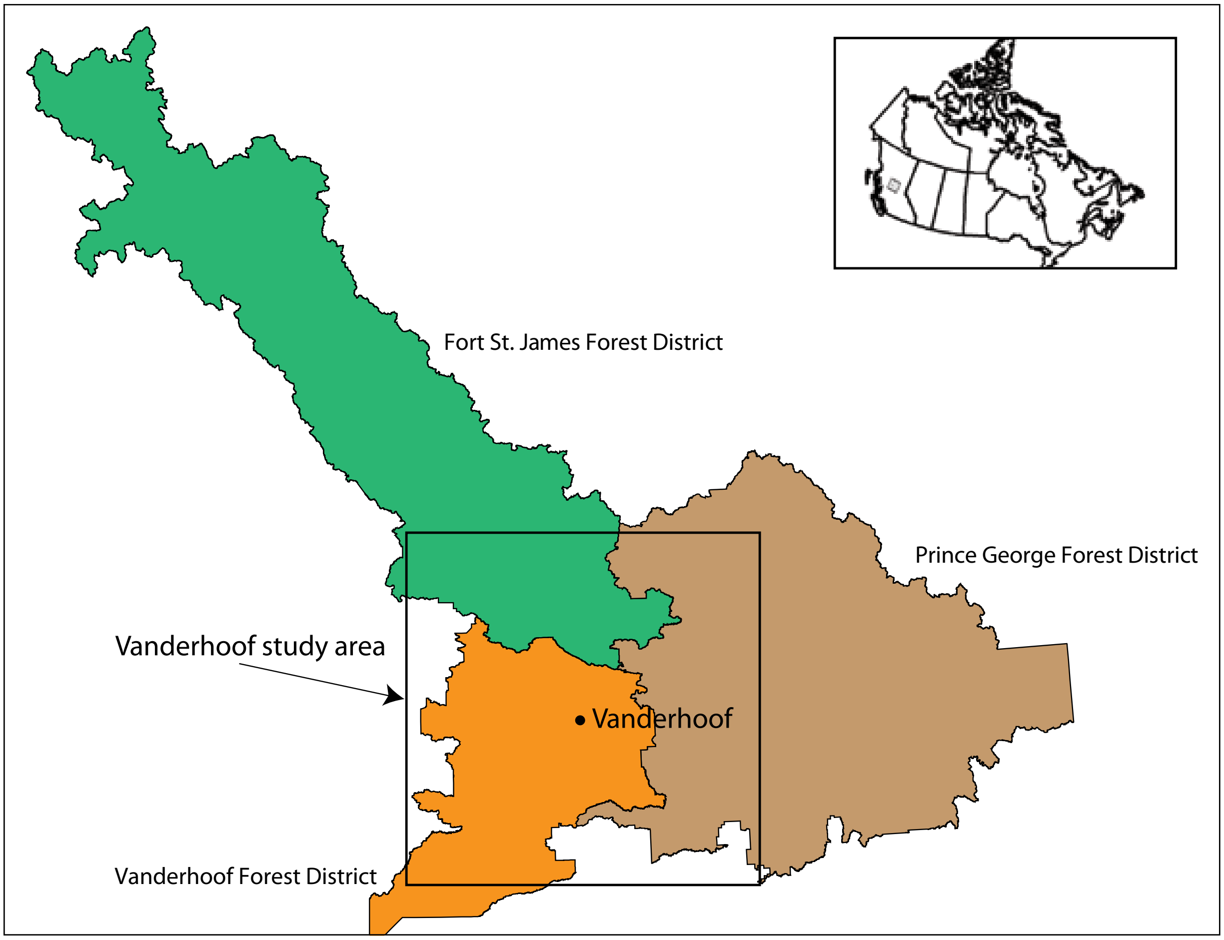


Figure 6. **The Prince George Timber Supply Area, with the Vanderhoof study area identified.**

THE COMMUNITY OF VANDERHOOF

Community Overview

A community overview serves a number of purposes in an assessment of vulnerability:

- identifying areas where the community may be sensitive to climate change, for which more systematic assessment may be required
- providing a context for the assessment of vulnerability to climate change (i.e., assessing the potential impacts of climate change in the context of other issues and other types of impacts that may be affecting the community)
- providing information to readers who are unfamiliar with the case study community
- providing a basis for understanding local institutions, social capital, and local adaptive capacity

The Community

Vanderhoof is a midsized rural community (population 4 400) located at the geographic center of the province of British Columbia (Figure 3) (Park, J. 2005. The District Municipality of Vanderhoof: community profile. Avison Management Services, Vanderhoof, BC. Unpublished report). The community is situated on the Nechako River near the junction of Highways 16 and 27. Highway 16 runs east toward Prince George (population 77 000), at a distance of about 100 km, and west toward Prince Rupert (population 15 000), about 700 km distant. Highway 27 runs north to Fort St. James.

The community was founded in the early 1900s by Herbert Vanderhoof, an American publicist hired by the Grand Trunk Pacific Development Company. After the rail line was constructed, Vanderhoof marked out the town site and was then tasked with luring settlers to the area to farm and settle the valley. Prospective ranchers and loggers soon occupied the area, and the community of Vanderhoof was established. The name Vanderhoof honors Herbert Vanderhoof but is also a Dutch term meaning "of the farm." The town's name has turned out to be appropriate, in that Vanderhoof became the first agricultural settlement in British Columbia and was eventually incorporated as the Village of Vanderhoof in 1926. The area's population declined during the Second World War. However, once the war ended, lumber demand and prices started to rise and Vanderhoof's logging industry began to grow. Growth of the local forest industry fueled the arrival of many new residents, and population growth resumed. Another boost to Vanderhoof's economy occurred in the early 1950s with the construction of the Kenny Dam on the Nechako River (located south of the town of Vanderhoof). The primary source of the population influx was the workers who constructed the dam. Once the work was completed, many of these workers remained in the Vanderhoof area. The Historical Society of Vanderhoof has documented that the town's final population expansion occurred in the 1960s, with a large inundation of American immigrants to Vanderhoof and the surrounding areas. Today, Vanderhoof is classified as a district municipality on the basis of its current population and the size of the area it serves, and it has experienced a steady population growth rate of 2%–3% annually.

Vanderhoof's main industries are forestry, agriculture, and tourism, but the community is also a service center for the region, providing government, educational, health, retail, and other services to its own residents as well as to smaller communities and rural residents in the surrounding area. The total population that relies on these services is around 18 000 (Vanderhoof District Chamber of Commerce 2005).

The Local Economy

Vanderhoof is a well-established community with a long and rich history. Resource industries have been the mainstay of the economy since the town's inception. Although forestry and agriculture continue to dominate within the local economy, census data over the past two decades has shown a new trend. Manufacturing and logging-related employment has slowly declined, while employment in the retail trade and in accommodation, health, social, and educational services has increased. Although it is unlikely that the community of Vanderhoof will cease to rely on natural resource based industry, there is a noticeable trend away from the primary industries toward service-based industries. That being said, the present-day local economy continues to be based on forestry, agriculture, and tourism.

Forestry is the leading industry in the Vanderhoof area, accounting for approximately 39% of all jobs and 63% of the community's economic base (according to an analysis by W.A. White, Canadian Forest Service, Northern Forestry Centre, Edmonton, Alberta). A number of mills operate in the Vanderhoof area, including Canadian Forest Products Ltd. (Canfor), L&M Lumber, Premium Pellet, and Vanderhoof Specialty Wood Products. Logging contractors, trucking companies, and the service industries that support the primary producers are also present within Vanderhoof. The traditional allowable harvest rate in the VFD was around 2 million m^3 yr^{-1}, but the VFD currently has an annual allowable harvest level of 6.5 million m^3 because of a recent uplift to permit the salvage of beetle-infested timber (Pedersen 2004). This timber supply flows through the above-mentioned mills, as well as another Canfor mill at Isle Pierre and the Fraser Lake sawmills near the Village of Fraser Lake. Numerous woodlot license operators and a variety of independent loggers (whose activity is administered through British Columbia Timber Sales) also provide timber to area mills. With such a high annual cut, forestry will continue as Vanderhoof's leading industry in the near future. However, forecasts of timber supply once the mountain pine beetle (MPB) outbreak has subsided (i.e., within 10 to 15 years) indicate an annual allowable harvest between 1.0 million and 1.6 million m^3 (Pedersen 2004). Although employment from forestry will decline from today's levels and will then continue to rise and fall throughout future decades, forestry is ultimately expected to always be an important part of the local economy.

Timber supply within the VFD has been reviewed and assessed regularly over the past few years because of the MPB outbreak. The major forest companies operating in the district do so generally under volume-based replaceable and nonreplaceable forest licenses. As part of the strategy to salvage beetle-infested timber, many short-term, nonreplaceable forest licenses and a variety of timber sales administered through the Stuart Nechako office of British Columbia Timber Sales have been awarded and will continue to be awarded to successful bidders.

The Vanderhoof Chamber of Commerce has identified agriculture as the second-largest industry in the area, with approximately 470 farms and ranches throughout the region. Agriculture accounts for about 11% of local employment and also generates over $23 million annually in gross farm receipts. The Nechako Agricultural Region encompasses approximately 3.4 million ha (1 ha = 2.471 acres) and actual deeded agricultural land accounts for approximately 121 000 ha, making the Nechako Valley the third-largest agricultural region in British Columbia. Most of the deeded agricultural land occurs along river valleys and low-lying hills in the region. These areas are generally composed of fertile and finely textured soils. The Nechako Valley is the second largest forage-producing region in the province. Cattle production is the predominant commodity of the Nechako Valley region, and over 39 000 head are produced per year. Thousands of hectares of grain, forage, and pasture are required to sustain the cattle herds, and the Nechako Valley produces enough feed for this purpose and also for the export of hay and grain. Grazing opportunities for cattle are also found in the forested areas throughout the VFD. In 1997, some 240 000 ha of forested land was under range tenure, which allowed 15 800 animal units of grazing on crown land. There are also several dairy producers, and greenhouse production of flowers, vegetables, and commercial organic produce has increased significantly in recent years. Farmers are also looking to new value-added production of free-range chickens and specialty herbs as secondary or primary cash crops.

The Nechako Valley Agriculture website (http://www.hwy16.com/nechakoag/) presents a useful summary of the interrelations between forestry and agriculture. As previously mentioned, forestry is the largest natural resource enterprise in the Vanderhoof region, requiring a huge land base for long-term sustainability. However, because of growing demand for agricultural land, these two industries have begun to compete for the same land base. Many policies and compromises will be required to develop compatible integration of these two resources in the Vanderhoof region. For example, much of the land surrounding the main agriculture basin consists of areas of good arability interspersed with rocky, pine-covered ridges. These lands are well suited for timber as well as for beef production. As the population of the Vanderhoof region increases, more demands will be placed on the land base, and there will be a need for continued commitment to integrated land management planning. For example, a recent pilot project resulted in the release of some MPB-salvaged forest land for sale or lease as agricultural land.

The recreation and tourism sector represents a growing industry for the community of Vanderhoof and the surrounding region. Commercial tourism depends on a variety of guiding and outfitting companies and several wilderness lodges. Visitors from other areas of British Columbia, other Canadian provinces, the United States, and other countries have all visited the Nechako Valley to view the landscape, undertake recreation in a wilderness environment, hunt wildlife, or engage in sportfishing. Access to the wilderness resource includes over 2 500 km of forest roads that give the public access to backcountry lakes, trails, and campsites. A number of commercial lodges are located near the District Municipality of Vanderhoof. Most commercial lodges are fully equipped with lakeside cabins, campsites, and restroom facilities, and some have shower facilities. Most lie on the shores of secluded lakes and therefore offer fishing opportunities and/or guiding expeditions into the backcountry for hunting or other wilderness experiences. Both summer and winter opportunities are available, and the majority of lodges in the area operate year-round.

Although tourism is somewhat dependent on the state of the area's forests, some speculate that it will increase as the forest industry begins to decrease once the high rates of salvage harvesting start to decline. However, visual esthetics are an important feature of the wilderness experience for many tourists, so there is also a chance that tourism opportunities will not increase until the forest landscape recovers from the impacts of beetle-related mortality and harvesting. Regardless of the state of the forests within the VFD, tourism opportunities are plentiful and readily available. Thus there are good opportunities for continued growth in the recreation and tourism industry in the future.

Vanderhoof has a relatively strong retail sector (including groceries, clothing, vehicles, and other merchandise). The community is the primary retail center for a number of neighboring communities, such as Fort Fraser, Fort St. James, and Fraser Lake. Prince George (97 km east of Vanderhoof) is the largest retail center in northern British Columbia. However, Vanderhoof residents and residents of nearby communities place value on spending locally and supporting local business.

Along with retail shopping, Vanderhoof offers a number of service-based businesses including accounting, advertising, banking, carpet cleaning, dry cleaning, accommodation, insurance, legal services, storage, and rentals, to name a few. A variety of service-based businesses are also required and available in Vanderhoof to support the three primary industries of forestry, agriculture, and tourism. Home-based business ventures offering products or services within the community and to surrounding areas are also on the increase.

Various other government, education, and health services are situated within Vanderhoof. A number of provincial agencies maintain offices in the community, including the Ministries of Forests and Range, Agriculture and Lands, Labour and Citizens' Services, and Transportation. A detachment of the Royal Canadian Mounted Police and a Canada Employment office are also located in Vanderhoof. A regional hospital and health care unit, as well as several dental and physiotherapy clinics, are located within the community. Vanderhoof has a community college, an adult education center, two high schools, and numerous elementary schools. Together, these institutions provide a range of services to the residents of Vanderhoof and the surrounding area, as well as providing local employment.

Groups, Facilities, and Activities within and around Vanderhoof

Vanderhoof offers many opportunities and amenities to local residents and visiting tourists. One local radio station and one local newspaper serve the community of Vanderhoof, along with two radio stations from Prince George and newspapers from Prince George, Fort St. James, and Vancouver. Numerous service organizations and clubs (e.g., Rotary Club, Vanderhoof Kinsmen Club, Elks Club, Vanderhoof community theatre) have chapters or are based within Vanderhoof. There is also an active Chamber of Commerce.

Vanderhoof is an active community. It hosts a variety of annual events supported by local organizations and groups, including Chamber of Commerce events, arts and cultural events, sports tournaments and other events, an annual recreation and leisure fair, and a variety of winter festivals. The community of Vanderhoof has a Recreation and Leisure Services Department with a full-time recreation coordinator to help organize events and to ensure that local residents are aware of available recreation and leisure opportunities. This department is committed to creating, supporting, enhancing, and promoting diverse community-based recreation opportunities and programs. A variety of service groups and community organizations help to fund, operate, and maintain many of the facilities in the community. The Recreation and Leisure Services Department works to ensure that use of these facilities is optimized. The availability of such a diverse range of sport, recreation, and cultural facilities in a small, rural locale like Vanderhoof ensures a good quality of life for current residents and potential newcomers to the community.

Outdoor recreation is important as a source of relaxation and renewal for area residents and visitors, and as a source of income for the local community and tourism operators (BC Ministry of

Agriculture and Lands 1997). The development of road access to the area's forests by the forest industry has created an abundance of recreation opportunities for local residents and visiting tourists, to view the landscape, observe or hunt wildlife, or enjoy other wilderness experiences. The VFD also supports approximately 39 B.C. Forest Service recreation sites ranging from vehicle-access campsites to more rugged, hike-in sites along the many rivers, lakes, and streams in the area. The district has 20 major identified hiking trails and numerous heritage and archaeological sites related to the presence of First Nations and early settlements in and around the VFD.

Current Issues

According to a survey of 18 local stakeholders conducted in early 2005 (Frenkel, B. 2005. Vanderhoof stakeholder study. Avison Management Services, Vanderhoof, BC. Unpublished report), the main issues facing Vanderhoof in the recent past, now, and in the future are mid-term and long-term timber supply; bovine spongiform encephalopathy (BSE, also known as mad cow disease); exposure to global markets and economic uncertainty; the local environment; the softwood lumber dispute with the United States; and opportunities for youth in the community. These issues are explored in more detail in this subsection.

Several environmental issues are relevant to the community of Vanderhoof, including but not limited to the current MPB outbreak, wildlife concerns, air quality, and the preservation and enhancement of populations of the Nechako white sturgeon.

The most important issue currently facing Vanderhoof is the MPB outbreak, which is having and will continue to have environmental, economic, and social impacts on the community. The most noticeable direct environmental impact is the expansive area of dead and/or dying lodgepole pine trees. An aerial view of the VFD shows a virtual sea of red trees, with scattered areas of timber harvesting from past and present attempts to contain the beetle or salvage the dying pine trees. The direct impact of the dead pine trees is severe, both ecologically and aesthetically. Although the indirect environmental impacts stemming from the MPB outbreak are speculative at this point, some potential issues can be identified:

- potential loss of a large carbon (C) pool from local forests that die as a result of beetle outbreak
- potential rise in ground and surface water tables due to a reduction in transpiration in the living forest
- potential accumulation of fuels, which may increase fire risk
- potential loss of wildlife habitat from death of the forest cover or from increased logging activity
- potential decrease in air quality (because of an increase in forest fire smoke)

In addition to the environmental effects, the MPB will also have significant socioeconomic impacts. The economies of Vanderhoof and nearby communities are currently experiencing increases due to increases in the level of salvage harvesting and forest product manufacturing. However, once the beetle outbreak has subsided and the remaining beetle-killed wood becomes unsalvageable, harvest levels, manufacturing output, and employment will begin to decline. Local residents have expressed concern about the future of the economy, wondering whether local employment opportunities will survive the aftermath of the beetle outbreak. The MPB outbreak has been anything but predictable, and the long-term impacts are uncertain.

Another environmental issue that has gained attention in Vanderhoof is the decline in the local population of Nechako white sturgeon. The white sturgeon is British Columbia's largest freshwater fish, and the Nechako River is home to a distinct population of this species, but it is in a serious state of decline. Many factors have contributed to the decline of the Nechako white sturgeon, including the construction of the Kenney Dam in the 1950s, which altered the flow, temperature, and turbidity of the Nechako River (Nechako White Sturgeon Recovery Initiative 2005). Another concern is that the population of this fish is not reproducing successfully. There are higher numbers of older fish in the river, with limited numbers of juveniles, which implies that the species is at risk. A Nechako white sturgeon recovery plan and corresponding recovery team have been developed to help preserve this species and to promote future growth of its populations.

Market access to the United States is an important issue for Vanderhoof and the surrounding communities because the economy is based largely on the production of commodities for export to other countries, primarily the United States. With forestry and agriculture being the top two local industries, restrictions on trade resulting from issues such as the softwood lumber dispute and the closing of foreign borders to Canadian beef products because of BSE can have a disruptive effect on the local economy. These two issues are now apparently resolved, but they illustrated the community's vulnerability to its reliance on the U.S. market as the major export destination for locally produced goods.

Climate Change as an Issue for Vanderhoof

One implication of climate change for communities such as Vanderhoof is the effects that such change will have on the primary renewable resource sectors, such as forestry, agriculture, and tourism, on which these communities rely economically. In particular, the importance of the forest industry sector to the economy of Vanderhoof and surrounding areas is clear. Forests are sensitive to climate, and climate change will likely lead to changes in forest conditions and therefore to changes in the local economy over the long term (Park, J. 2005. The District Municipality of Vanderhoof: community profile. Avison Management Services, Vanderhoof, BC. Unpublished report).

Although some impacts are expected, systematic assessments of the magnitude, direction, and timing of potential impacts have not yet been undertaken. The economic structure of communities may also affect the degree to which they are affected by climate change. For example, a high percentage of the labor force in Vanderhoof and the surrounding region works in occupations that are unique to timber harvesting and/or primary processing industries. As such, the skills and knowledge required for employment in these sectors may be sufficiently specialized that it is unique to these industries and to some extent nontransferable to other industries. If so, then economic restructuring (forced by climate-related pressures or other factors) could be limited by a lack of certain labor force skills required by new industries. This may have implications for the training and/or retraining programs included as part of any general adaptation strategy in resource-based communities. These conclusions are speculative, however, primarily because the extent and timing of climate impacts is not yet known. In addition, a far more in-depth assessment of the local labor force and skill requirements for potential new industries would be required. However, if the community of Vanderhoof were to begin looking at risk management strategies as a way of beginning to plan for climate change, some assessment of training and retraining requirements might be a consideration.

For a variety of reasons, the current MPB outbreak is the primary focus for local residents in their consideration of climate change. First, the impacts of the beetle outbreak are now being realized, although the long-term impacts remain uncertain. Second, the MPB outbreak is a tangible issue. Residents have witnessed the devastation and have been forced to consider the possible impacts of the outbreak in their day-to-day lives. Third, the ability of a community to maintain or increase its population is largely tied to the vitality of the local economy. People tend to migrate to where they can find and sustain gainful employment while enjoying a good quality of life. The biggest immediate threat to the socioeconomic health of Vanderhoof and the surrounding area is the MPB outbreak, not long-term climate change.

Summary

Vanderhoof is a well-established, tightly knit community with a core population that has strong ties to the community. The residents of Vanderhoof and those residing in the nearby rural areas also have significant economic and social ties to the surrounding forests. The potential therefore exists for significant economic and social impacts on the community as a result of climate change.

One factor that will bear on the ability of Vanderhoof to respond to future climate change is the effectiveness of local leadership in anticipating and planning for the impacts of this problem. Local leadership is active both within and outside the community, seeking new opportunities for Vanderhoof and its residents. The municipal government, long-time residents, and local leaders are dedicated to providing a high-quality lifestyle for Vanderhoof residents. Vanderhoof has strong institutions and strong ties that bind the community together. This suggests that, within the limits of their power and control, local government and local leaders will be an important asset as Vanderhoof addresses the changes it may face as a result of climate change.

Vanderhoof faces several potential challenges. First, although the community is currently booming, an economic decline can be expected within 10 years because of reductions in timber supply. Second, although the community is slowly diversifying, it remains heavily reliant on the forest industry and, to a lesser degree, on agriculture and tourism. Each of these sectors is sensitive to current climate and will be potentially affected by future climate change, and each sector has a specialized labor force with skill sets that are not necessarily directly transferable. Third, Vanderhoof's main economic sectors are based on exports, operating in a transforming and increasingly competitive global economy. Both climate-related and nonclimatic factors will lead to changes in global market structure that will affect the local economy. These changes will be over and above the local consequences of climate change on the climate-sensitive natural resources in the area and will require preparation and adaptation within the community of Vanderhoof. Planning is an important part of such preparation, but it requires data about the kinds of future outcomes that are possible. This study addresses information gaps pertaining to potential sources of vulnerability to climate change in Vanderhoof.

Survey of Local Stakeholders about Climate Change

The willingness and/or ability of decision makers to undertake planned adaptation to climate change and climate-related risks will depend on how they view those risks. There is a significant literature on the forces that affect the social construction of risk (Slovik 2000). Two important factors are one's sources of information and the extent to which one trusts those sources. Local leaders are an important source of information in communities. Such leaders (both formal and informal) generally have significant networks both within and outside of communities. They are a conduit for information flowing into the community from external sources and in the opposite direction. This is not to suggest that local leaders have a monopoly on information flows (for example, the Internet allows for greater levels of individual awareness and access to information than at any previous time in history) or that the views and opinions of community residents will mirror those of community leaders. It is likely, however, that community leaders will have some influence on the opinions and perceptions of others in the local community. Moreover, community-level responses to issues like climate change and/or large-scale decisions with community-wide implications are likely to be made by local leaders. Thus, an understanding of the opinions and perceptions of local leaders themselves may provide important insights into the extent to which a community like Vanderhoof sees climate change as a salient issue and the degree of convergence in viewpoints about climate change. These insights in turn provide an indication of the degree to which the community is prepared and willing to undertake planned adaptation at both the individual and the community level.

A survey of key local stakeholders in Vanderhoof was conducted in early 2005 (by Avison Management Services Ltd.) to identify their views, opinions, and perceptions about climate change. Initially, 22 individuals were selected from the Vanderhoof Land and Resource Management Plan stakeholder list, of whom 18 agreed to participate in the survey. The respondents represented a range of sectors from the Vanderhoof area (see Table 1 for a distribution by participant type). However, the survey was not based on statistical sampling, so the results should not be considered representative of the Vanderhoof population. Survey respondents did come from the major resource sectors supporting the Vanderhoof economy and were stakeholders in the Vanderhoof Land and Resource Management Plan, so they can be considered active and knowledgeable citizens.

A semistructured interview approach was employed. The questions pertained to the issues facing Vanderhoof (see previous section), respondents' concerns about climate change, observed evidence of climate change (discussed in the next main section, entitled "Climate of the Vanderhoof Study Area"), potential impacts of climate change, and adaptations to climate change. The results for three of these sections of the survey (concerns about, potential impacts of, and adaptations to climate change) are discussed in the following sections.

Table 1. Breakdown of key local stakeholders in Vanderhoof who responded to a survey about perceptions of climate change[a]

Participant type	No. of respondents
Government	3
Agriculture	2
Forest industry	3
Other stakeholders	6
General public	4

[a]Of the 22 individuals approached to participate in the survey, 4 did not respond.

Concerns about Climate Change

Half of the respondents were definitely or extremely concerned about climate change and the remainder were somewhat or not concerned (Table 2). Similarly, a winter 2005 survey of the Canadian public conducted for Natural Resources Canada found that 52% of Canadians were very concerned about climate change. The relatively high level of concern in Vanderhoof may be due to the MPB outbreak and the general realization that its spread is due at least in part to warmer winters. One interesting result was that respondents from the Vanderhoof agricultural sector were less concerned about climate change than those from the forest sector. Respondents from the agriculture sector felt that current weather patterns are part of a naturally occurring, longer-term weather cycle. All of the forestry respondents were of the view that climate change has already negatively affected the forest around Vanderhoof.

Table 2. Degree of concern about climate change among respondents

Degree of concern	No. (%) of respondents
Extremely concerned	3 (17)
Definitely concerned	6 (33)
Somewhat concerned	7 (39)
Not really concerned	2 (11)

Given that 89% of respondents were either "somewhat concerned" or more concerned, it seems safe to conclude that climate change is on the minds of the majority of respondents. Their main concern seemed related to long-term environmental impacts and general impacts on the community and the local economy (Table 3). Concerns about current or short-term impacts to the individual or his/her family were ranked lowest.

Table 3. Type of concern about climate change among respondents

Type of concern	No. (%) respondents[a]
Current or short-term impacts on you and your family	5 (28)
Long-term environmental impacts	10 (56)
Impacts on the community and on the local economy	10 (56)
Impacts on future generations	10 (56)

[a]Respondents could pick more than one item.

Potential Impacts of Climate Change

Tables 4, 5, and 6 summarize respondents' views about the potential impacts of climate change in Vanderhoof. At a general level, respondents saw the main positive benefits taking the form of milder winters and the fact that climate change will motivate economic diversification and innovation (Table 4). Some respondents mentioned that growing seasons would be longer, but there was no indication that respondents felt this would translate into increased timber supply. Many of the views and perceptions about potential negative impacts were related to the MPB and therefore, quite naturally, this specific incident had a strong influence on views about climate change. Respondents felt that there would be a reduction in harvesting opportunities due to shorter winters and wetter summers.

Respondents generally felt that the impacts of climate change on local plants species would be negative (Table 5). The only positive effect identified related to forage crops, but that was countered to some degree by the suggestion that the impacts on alfalfa could be negative. The potential impacts on most wildlife species were also seen as negative (Table 6). The views and opinions about the impacts of climate change on plant and wildlife species were linked to the MPB outbreak. One respondent mentioned that rapid salvage of beetle-killed timber would require a significant increase in road access into forested areas. This has the potential to increase hunter and predator pressure on ungulates. Thus, increases in ungulate habitat and in their winter survival associated with climate change might be offset to some extent by increased hunter and predator pressure.

Adapting to Climate Change

The survey respondents were confident that the community of Vanderhoof and the residents of the Nechako Valley would be able to adapt to climate change. They felt that the area's residents are entrepreneurial, and this approach could be effective especially if the changes occur gradually. The region has faced several obstacles and challenges over the years and has always developed solutions that have allowed it to move forward. Respondents therefore felt that the region has the necessary skills and experience to adapt and adjust to the effects of climate change.

Conclusions and Implications

Through the survey, a clear local voice was heard indicating that something has changed over the past 20 to 30 years (see the subsection "Stakeholder Observations of Local Climate Change" in the section entitled "Climate of the Vanderhoof Study Area"); there was general agreement that the overall climate is changing, with some differences of opinion as to whether these changes are part of a natural pattern or due to other factors. The respondents felt that impacts would occur and that there would be more negative than positive impacts. Importantly, the respondents had confidence in the region's ability to adapt, and they were optimistic that adaptation would occur when and where justified.

The results of this survey of stakeholders and leaders have implications for the community's "willingness to adapt." First, local views and perceptions of climate change were, as expected, influenced by the recent MPB outbreak. Nevertheless, there was recognition and acknowledgement of the broader issue of climate change. The community leaders were thinking about it and were somewhat concerned about local impacts. Therefore, lack of awareness of climate change may not be a factor impeding adaptation decisions where they are warranted, at least in terms of the stakeholders consulted in the survey.

A second general result is that many of the comments pertained to events occurring at the time of the survey or expected to occur in the near future, not necessarily events that might occur in the longer term (e.g., a change in the fire regime, market changes, changes in species composition of the forest). People tend to be more concerned about issues that are more immediate and more tangible and less concerned about far-off, intangible issues. It can be expected, therefore, that adaptive response to immediate and currently evident impacts will be more easily rationalized than current adaptation to long-term future impacts.

Table 4. Respondents' views on potential general impacts of climate change

Positive impacts
Easier winters, less snow, less extreme temperatures
Longer frost-free periods, longer growing season
Opportunity to spend more time outdoors
Requirement for community to look at ways to diversify
Requirement to develop new farming and logging equipment to meet the needs associated with a changing climate (e.g., lower ground pressure equipment)
Negative impacts
Negative economic effects due to lack of timber supply in the mid to long term as a result of the mountain pine beetle infestation
Need to study environmental issues in the "dead red pine forest"
Increase in invasive and noxious plants
Change in forest stand composition
Potential local impacts of global climate change
Loss of harvesting opportunity (winters not as cold and summers likely wetter because of lack of tree cover to take up water)
Increase in skin cancers
Flourishing of pests such as mountain pine beetle when cold winters do not occur (as is currently the case)
Higher water levels in lakes and rivers
Increase in winter kill of forage crops such as alfalfa due to earlier freeze–thaw cycles
Shallower snow pack (with recreational and economic impacts)
Required change in economic environment

Table 5. Respondents' views about potential impacts of climate change on plant species

Species of concern[a]	Negative or positive impact	Reason
Pine trees and arboreal lichens	Negative	Death of pine trees will open up large areas of the land base and dry up the forest floor.
Noxious and invasive plants	Negative	A warmer climate may allow the introduction of new invasive plants or outbreaks of naturally occurring noxious plants.
Forage crops	Positive	It might be possible to grow plant species or varieties that have not been grown in the valley before.
Lodgepole pine	Negative	Warmer winters will occur.
Alfalfa	Negative	If a drier trend continues, the protein content in the alfalfa will decrease. Also, winter kill in alfalfa crops is being noticed because of warmer winters.
Moss layer of pine forests	Negative	The feather mosses will dry up when the pine forest dies.
Fairy slipper orchid and other shade species	Negative	Species that require shade will be lost when the pine forest dies.

[a]Categories as identified by respondents.

Table 6. Respondents' views about potential impacts of climate change on wildlife

Species of concern[a]	Negative or positive impact	Reason
Pine marten	Negative	Large tracts of pine forest are being destroyed by pine beetle.
Pine grosbeak	Negative	Large tracts of pine forest are being destroyed by pine beetle.
Ungulates	Positive	Regeneration of pine forest will increase feed, and survival rates are up because of warmer winters.
Fish	Negative	Water temperatures may rise because of loss of forest cover.
Caribou	Negative	Lichens in old-growth forest, a source of food for caribou, is being lost as the forest is ravaged by beetles.
Furbearers (marten, lynx, etc.)	Negative	It is hard for these species to survive when large areas of pine forest are destroyed by pine beetle and salvage logging.
Black bear	Negative or positive	The bear population has increased.
Birds	Negative or positive	More species now occur in the area, with some species overwintering.
Deer	Negative or positive	The deer population is increasing, but this has been followed by an increase in predator populations (cougar, wolf, bear).
Moose	Negative	The moose population may be declining slightly.
Wolves and coyotes	Negative	The predator population has increased 10 times since the 1960s.
Squirrel	Negative	Less food is available because of lack of cones from pine trees.
Fisher	Positive	Populations should increase when the pine stands regenerate (more rabbits, etc.).

[a]Categories as identified by respondents.

CLIMATE OF THE VANDERHOOF STUDY AREA

Between 1906 and 2005, the global mean temperature increased by approximately 0.74 ºC (Solomon et al. 2007). It is generally accepted, however, that this increase masks much greater (or in some cases smaller or negative) temperature changes for different regions of the globe. Hence, for community (or regional) studies, it is necessary to evaluate past and projected future climate for specific locations and at scales that are relevant to decision makers at those levels. To date, there has been no comprehensive analysis of the 20th century climate record and future climate for the Vanderhoof region. This section combines historical data, local stakeholder observations, and outputs from future climate scenario modeling to assess past, present, and future climate in the Vanderhoof study area.

Historical Climate Record

As noted elsewhere in this report, the pine-dominated forests in the Vanderhoof region are undergoing an unprecedented outbreak of the MPB. Experts have suggested that this attack is at least partly due to an unusually long sequence of abnormally mild winters (e.g., Carroll et al. 2004). The socioeconomic consequences of forest losses due to the MPB on the Vanderhoof community are likely to be significant. This event illustrates how climate and climate change may contribute to change and to socioeconomic impacts in resource-based economies.[2] However, climate influences the populations in communities like Vanderhoof in many other ways. First, climate and climate variability affect many aspects of rural life, including agricultural output, tourism, and forestry operations. Second, residents of rural communities have a strong association with the outdoors and an intimate knowledge of the climate of their region and how it influences features of the surrounding landscape. They may sense or detect subtle changes in local climate and/or changes in the landscape that could be tied to climate change long before scientific evidence becomes available. Moreover, from a lifestyle perspective, they may look upon changes in climate favorably (e.g., more pleasant winters) or unfavorably (e.g., summers becoming too hot and dry), or they may be indifferent. Thus, the economic livelihoods, quality of life, and relationships to the outdoors and the surrounding landscape of many individuals residing in resource-based communities such as Vanderhoof are affected by the local climate.

This section combines local residents' personal observations of climate-related changes with statistical analysis of historical climate data compiled for the study area over the last 100 years. The purposes of this discussion are to assess trends in climate over the past century in the Vanderhoof area, to determine whether there is statistical evidence of climate change, and to relate historical data to the observations of local residents.

Definitions

Before discussing the climate history of the Vanderhoof study area, it is appropriate to define the terms "climate," "climate change," and "climate variability." The Intergovernmental Panel on Climate Change (see Houghton et al. 2001) has defined these terms as follows:

Climate: Climate in a narrow sense is usually defined as the "average weather," or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands of years. The classical period is 3 decades, as defined by the World Meteorological Organization (WMO). These quantities are most often surface variables such as temperature, precipitation, and wind.

Climate change: Climate change refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the *United Nations Framework Convention*

[2] It is important to note that the reasons for widespread events like the MPB outbreak are often complex and multidimensional. Therefore, in reality, a change in local climate may be only partly responsible for the current outbreak, and continued warming may in fact have detrimental effects on beetle populations (Carroll et al. 2004; Logan and Powell 2004).

on Climate Change (UNFCCC), which defines "climate change" as: "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods."

Climate variability: Climate variability refers to variations in the mean state and other statistics (such as variances, the occurrence of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events.

Data Sources

Historical climate data for the Vanderhoof study area were obtained from a common database developed by the Canadian Forest Service (see McKenney et al. 2006). This data set is based on a fixed grid covering Canada and the United States at approximately 10 km × 10 km resolution. All of the data used in the present study share a common subregion centered on Vanderhoof (Figure 3). Because the instrumentation needed to measure variables other than temperature and rainfall tends to be more sophisticated and expensive, long-term historical data on radiation, humidity, and wind speed are much rarer, particularly for rural areas of the country. For the issue of climate change at least, it is the long-term trends in temperature and precipitation that are of greatest interest (although there is also increasing concern about changes in climate variability and changes in the frequency of what are now considered "extreme events"). Hence, the historical data sets include 100-year time series for temperature and precipitation, but only 30-year monthly climate "normals" for the other variables.

The historical climate data for the Vanderhoof study area, as described in this section, were extracted from a continental-scale data set of historical monthly mean daily minimum and maximum temperatures and total precipitation, observed at climate stations across Canada and the USA from 1901 to 2000 (McKenney et al. 2006). In addition to climate records made available by the US National Weather Service and Environment Canada, data were obtained from BC Hydro climate stations located in remote mountainous regions of British Columbia. The location-specific climate records were interpolated using the ANUSPLIN software package (Hutchinson 2004). This method assumes that values for any climate variable can be estimated at any geographic location as a function of position and elevation within the overall network of climate stations. Various statistical tests are applied to ensure that the estimated value is consistent with observed data and the known characteristics of each climate variable. For example, precipitation is known to be much more spatially variable than temperature, so more precipitation measurement stations are needed to estimate precipitation with the same level of reliability as temperature. Conversely, confidence in precipitation estimates will be lower than that for temperature estimates from a given number of climate stations. The station network in Canada was sparsest in the early 20th century, but reached a maximum in the 1960s and 1970s before funding cuts forced the closure of some stations in recent years. This variation has affected the error estimate in the ANUSPLIN models over time. The overall mean errors appear to be about 1.0 °C to 1.5 °C for temperature and 20%–40% for precipitation (McKenney et al. 2006).

The ANUSPLIN software fits a unique solution "surface" to the observed data for each variable, where a single month (or year or 30-year normal) of a single climate factor is considered to represent one variable, derived from all of the available station data. This solution can then be used to predict values at any point or points within the area over which the climate station data were obtained. ANUSPLIN is entirely statistical in its approach and does not attempt to correct for slope and aspect, for example, when interpolating precipitation, wind, or temperature in mountainous regions. ANUSPLIN was used to create continental-scale "spatial coverages" of monthly data on a grid with 1/12 degree latitude by 1/12 degree longitude (approximately 10 km) resolution. For the Vanderhoof region, three more steps were needed. First, the original 1/12-degree resolution grids were resampled using ARC/INFO geographic information system software to create a 10-km resolution grid for Canada on the Lambert conformal conic projection (a format commonly used for maps of Canada because it reduces aerial distortion). Second, all of the gridded data for each month in a rectangle of approximately 350 Lambert conformal conic grid cells, centered on Vanderhoof, were averaged to produce 100-year data sets, for each of monthly maximum and minimum temperatures and precipitation. Finally, the seasonal averages were calculated from the monthly data (see the section "Climate History").

Trends in mean climate over the 100-year period were tracked by calculating a 10-year moving average and superimposing this trend line on the annual data. Extremes and variability are represented by maximum and minimum values and by the observed variation of the annual values around the moving average.

Climate History

This section provides a description of climate trends for monthly mean daily minimum and maximum temperatures and precipitation in the Vanderhoof study area for the period 1901 to 2000. Although other climate variables could have been considered, their long-term records are generally less reliable. In any case, temperature and precipitation are the variables commonly used for describing climate.

In the analysis here, each variable is reported on a seasonal basis (i.e., the average temperatures or total precipitation for each season, where seasons are defined as follows: spring, March–May; summer, June–August; fall, September–November; and winter, December–February, where December data are taken from the previous year).

Annual values and the 10-year moving averages for precipitation (by season) in the Vanderhoof study area for the period 1901 to 2000 are shown in Figures 7 to 10. Visual inspection of these graphs shows that summer precipitation is the most variable and spring precipitation the least variable. The trend lines indicate that precipitation levels were at their lowest levels in the 1930s. Precipitation in all seasons increased until the mid-1960s (as indicated by the 10-year moving averages). Since then, the 10-year average spring, summer, and fall precipitation has generally fluctuated around the current 30-year normals, but winter precipitation peaked around 1973 (at 162 mm) and has declined since the 1980s.

Figures 11 to 14 show the annual means and 10-year moving averages for seasonal mean daily minimum and maximum temperatures over the period 1901 to 2000. Three key results are evident. First, there is strong evidence of a general warming trend, with the 1990s being the warmest decade of the 20th century. Second, the mean daily *minimum* temperature in the Vanderhoof region has increased, while the overall trend in *maximum* temperature has shown little change (i.e., the warming trend is dominated by increased nighttime minimums in all seasons). Third, and closely related to the second result, there has been a general decrease in diurnal temperature range. In addition, temperature variability has been greatest in winter. This variability is related to the greater tendency for dense, cold, stable air masses to accumulate near the surface at inland locations in winter, whereas surface heating and convective mixing occur more frequently in the warmer months and in coastal regions. These observations are entirely consistent with the findings of several other studies of historical climate data around the globe (Karl et al. 1991; Easterling et al. 1997; Heino et al. 1999; Plummer et al. 1999). The Vanderhoof data also indicates that winter and spring minimum temperatures in particular have become warmer, which also implies that the frequency and/or duration of extremely cold winters has declined. Similar differences in warming trends for maximum and minimum temperatures have been widely predicted by global climate models, most of which have also predicted greater warming in winter than in summer for inland regions.

At the local scale, this trend of increasingly warm winters is likely to be the climatic trigger for the MBP outbreak in central British Columbia. Whereas many concerns about climate warming relate to summer maximum temperatures more frequently exceeding the coping ranges of local environmental and socioeconomic systems, this outbreak is an example of an ecological impact that has been triggered or exacerbated by an upward trend in winter minima.

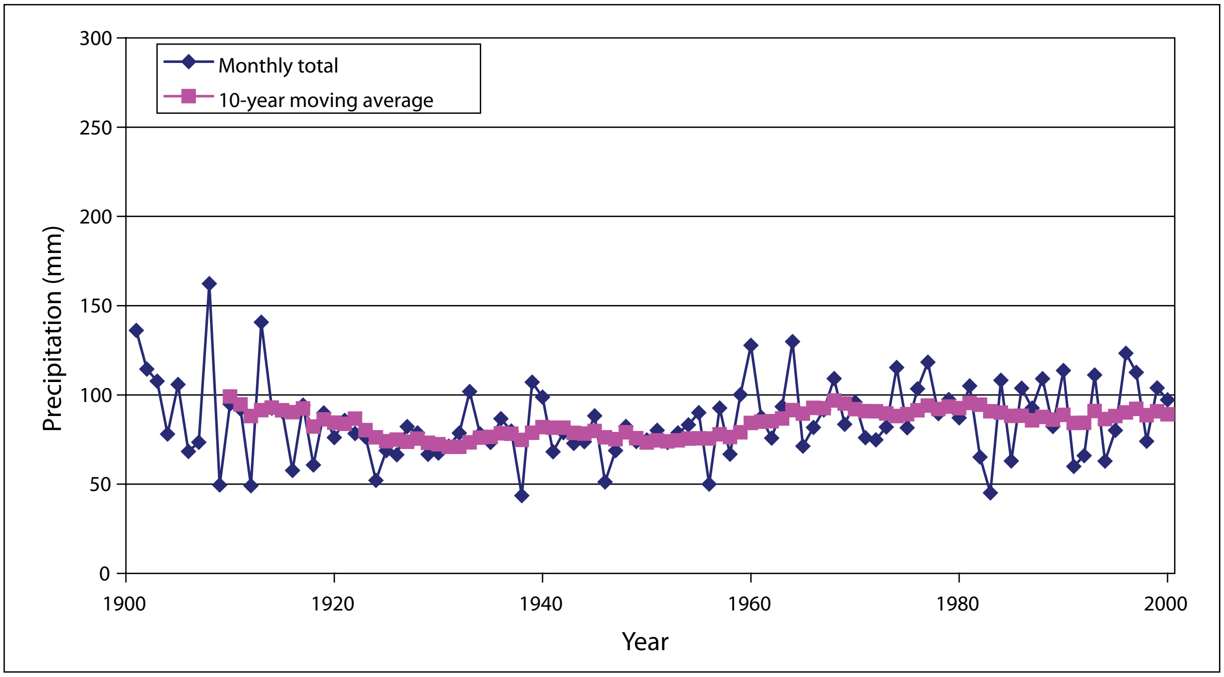


Figure 7. Spring monthly precipitation in the Vanderhoof region, 1901–2000.

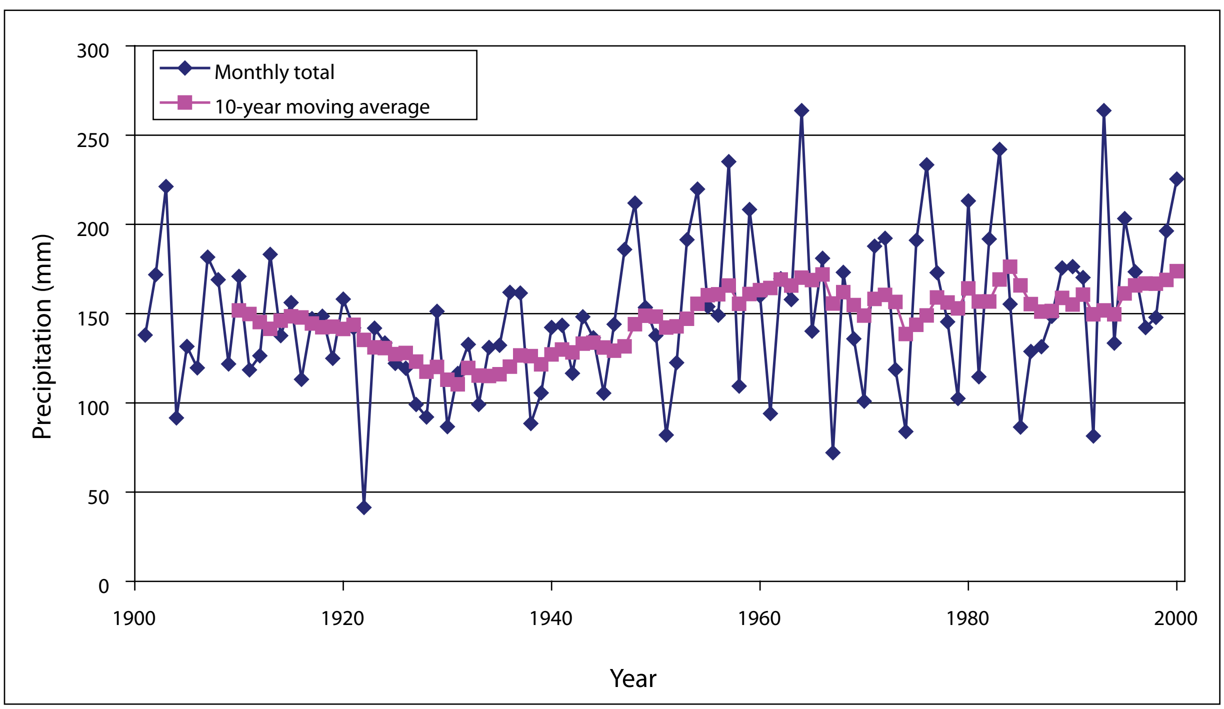


Figure 8. Summer monthly precipitation in the Vanderhoof region, 1901–2000.

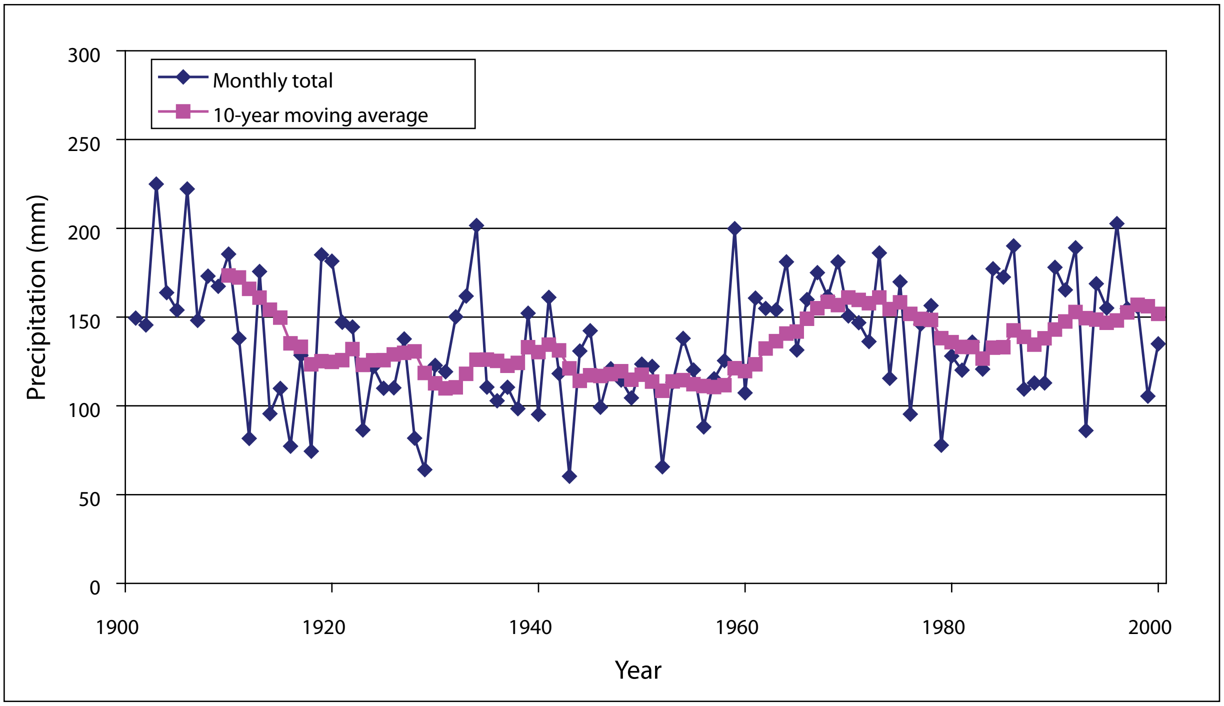


Figure 9. Fall monthly precipitation in the Vanderhoof region, 1901–2000.

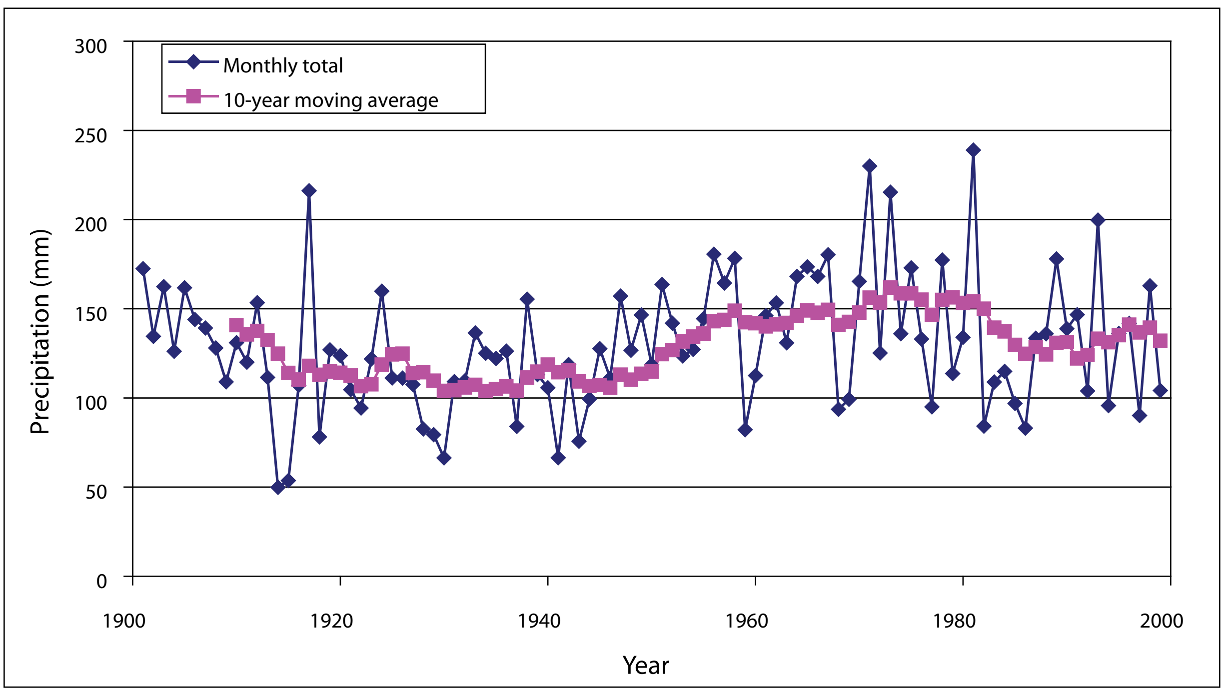


Figure 10. Winter monthly precipitation in the Vanderhoof region, 1901–2000.

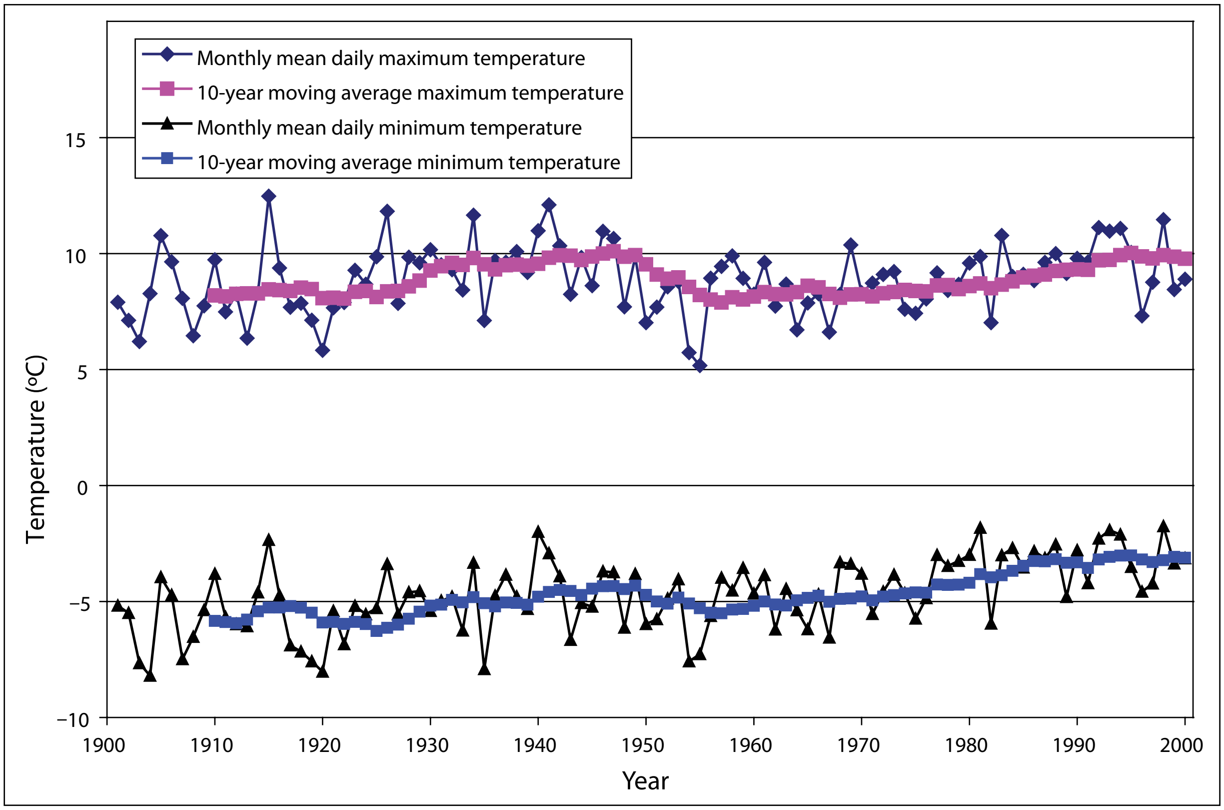


Figure 11. Spring monthly mean temperatures in the Vanderhoof region, 1901–2000.

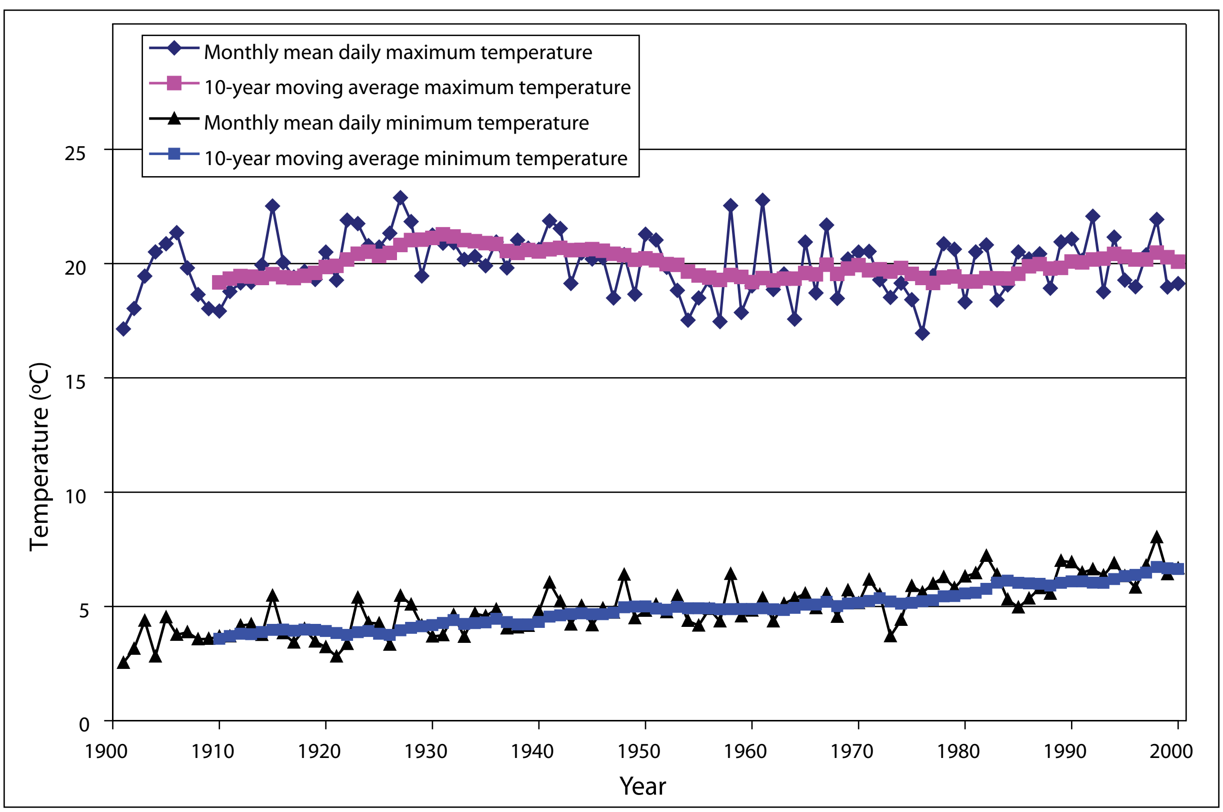


Figure 12. Summer monthly mean temperatures in the Vanderhoof region, 1901–2000.

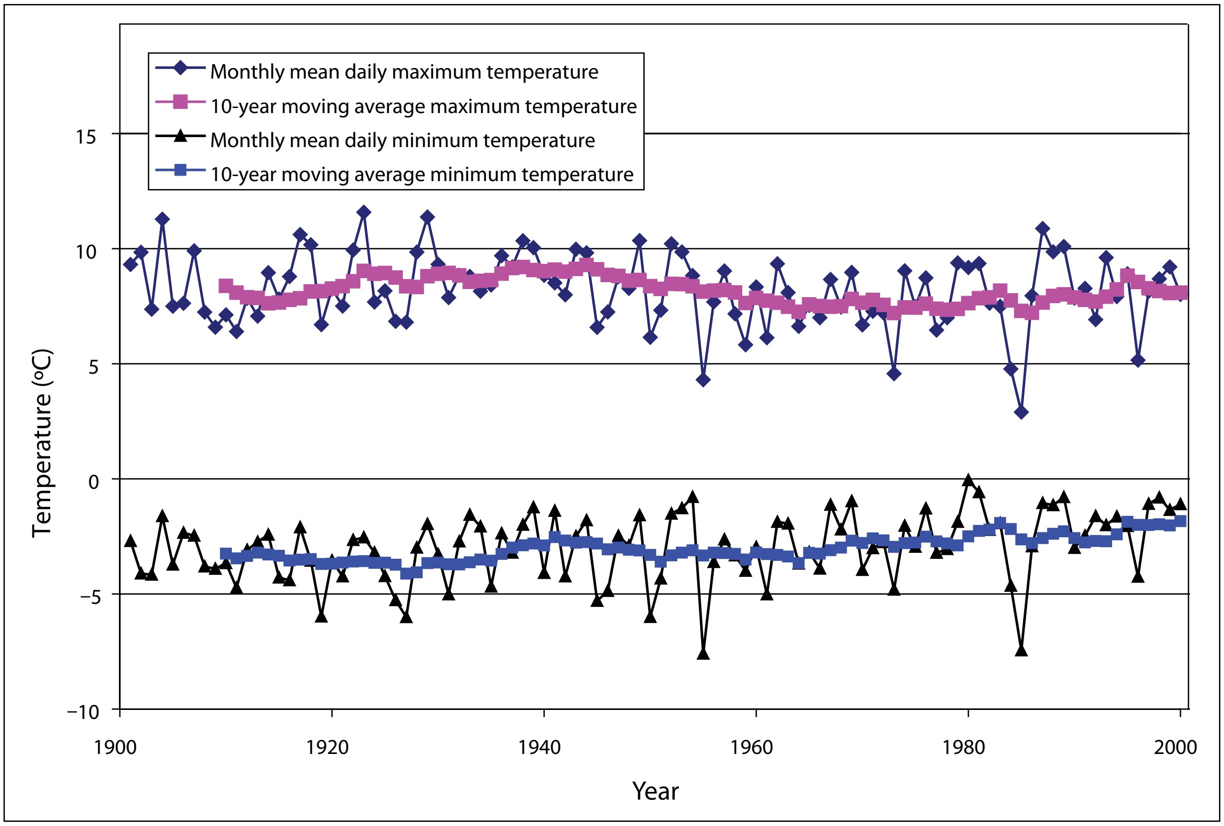


Figure 13. **Fall monthly mean temperatures in the Vanderhoof region, 1901–2000.**

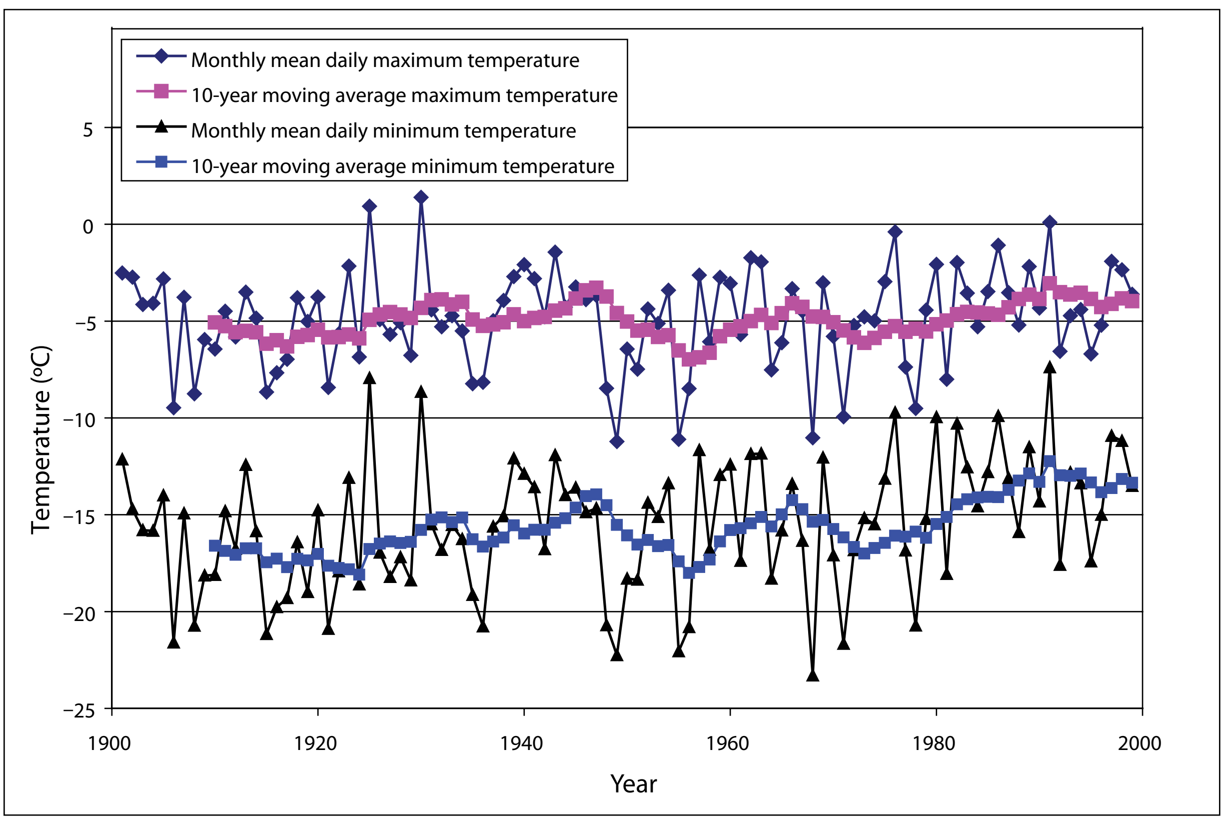


Figure 14. **Winter monthly mean temperatures in the Vanderhoof region, 1901–2000.**

Statistical Analysis of Decadal Means (1900–1999)

Figures 11 to 14 suggest that some changes occurred in the climate of the Vanderhoof region between 1901 and 2000. One of the clearest trends is an increase in the seasonal averages for monthly mean daily minimum temperature (T_{min}). However, the appearance of a trend is insufficient to conclude that warming has occurred. We therefore conducted a series of *t* tests to investigate whether the changes in decadal average T_{min} between 1901 and 2000 were statistically significant. Table 7 gives the decadal means and variances for T_{min} by season, and the individual *t*-test results comparing the decadal means for each season are provided in Tables 8 to 11, where shaded boxes indicate statistically significant differences.

Spring average T_{min} values in the 1990s, 1980s, and 1970s were significantly different (at the 95% confidence level, i.e., 5% probability of the results occurring by chance alone) from those in the 1900s (Table 8). Similarly, average T_{min} values in the 1990s and 1980s were significantly different from those in the 1910s. In other words, spring T_{min} values were significantly warmer at the end of the 20th century than at its beginning. In general, spring T_{min} in the 1990s were statistically significantly warmer ($P < 0.05$) than those in all other decades of the 20th century, with the one exception of the difference in means between the 1990s and 1980s.

The warming trend in the Vanderhoof region was even more significant for summers (Table 9). Summer average T_{min} was about 3.6 ºC in the 1900s but over 6.6 ºC in the 1990s (Table 7). Moreover, summer average T_{min} in the 1990s was significantly higher than in any other decade except the 1980s. The long-term historical trend seems clear, with very high probabilities that the differences in average daily minimum temperature between the 1900s and the 1990s are statistically significant.

Statistically significant signals in terms of differences in fall and winter T_{min} values over the period 1900 to 1999 (Tables 10 and 11) are less prominent, partly because of greater variability, particularly in winter T_{min}. Mean winter T_{min} for the 1990s was statistically significantly higher than mean winter T_{min} in the 1910s and 1930s (Table 11), and fall T_{min} values in the 1990s were statistically higher than in most of the previous decades of the century (Table 10).

Stakeholder Observations of Local Climate Change

This analysis indicates that statistically significant warming has occurred in the Vanderhoof region, particularly since 1970. Changes over the past 35 years are well within living memory, and as such many local residents might have noticed environmental changes related to this warming. In an interview survey of 18 Vanderhoof stakeholders, 16 respondents reported evidence suggesting that the climate has changed appreciably, although some also suggested that the observed changes might be due to a natural weather cycle (Frenkel, B. 2005. Vanderhoof stakeholder study. Avison Management Services, Vanderhoof, BC. Unpublished report). Respondents reported the following observations:

- more abrupt and more severe weather events (winds, storms)
- milder winters
- shorter winter logging season
- increased stream flows
- shallower snow packs in the valley
- thinner ice forming on water courses
- new bird species in the area
- overwintering of some bird species that used to migrate
- increase in winter kill of forage crops due to freeze–thaw cycles
- "blending" of the four seasons

Although the survey sample size was small, these impressions of change are largely consistent with the trends noted in the statistical analysis of interpolated regional data described earlier and represent further supporting evidence of the occurrence of climate change in Vanderhoof over the past 35 years. Other studies have attributed observed changes in environmental conditions to historical climate change. Leith and Whitfield (1998), for example, found that spring runoff is occurring earlier and that snow packs are shallower in south-central British Columbia, resulting in lower but longer duration summer stream flows. More generally, some studies in the

Table 7. Average daily temperature minima (°C) by decade for each season for Vanderhoof

Season	Parameter	1900–1909	1910–1919	1920–1929	1930–1939	1940–1949	1950–1959	1960–1969	1970–1979	1980–1989	1990–1999
Spring	Average	−5.84	−5.91	−5.18	−4.80	−4.71	−5.19	−4.79	−4.19	−3.31	−3.11
	Variance	2.42	2.85	0.79	2.56	1.60	1.87	1.51	1.04	1.46	1.08
Summer	Average	3.59	3.92	4.18	4.32	5.00	4.89	5.16	5.57	6.09	6.64
	Variance	0.39	0.40	0.83	0.19	0.53	0.44	0.20	0.73	0.65	0.33
Fall	Average	−3.25	−3.69	−3.64	−2.89	−3.31	−3.20	−2.79	−2.50	−2.57	−1.84
	Variance	0.79	1.40	1.63	1.73	2.77	3.79	1.84	1.64	4.49	0.97
Winter	Average	−16.60	−17.03	−15.79	−15.97	−16.07	−15.79	−15.74	−15.48	−13.30	−13.25
	Variance	8.98	7.40	19.35	6.63	11.38	12.97	13.10	15.40	6.28	9.28

northeastern United States have shown that the frost-free season is arriving earlier (Cooter and LeDuc 1995; Easterling et al. 2000), whereas DeGaetano (1996) reported a trend toward fewer days of extreme cold. Several researchers have found that increases in the number of frost-free days are coincident with a general increase in average daily minimum temperatures (Easterling et al. 1997; Heino et al. 1999; Plummer et al. 1999; Kunkel et al. 2004).

Conclusions and Discussion

Climate data and stakeholder observations strongly suggest that, in common with many midcontinental regions of Canada, significant climate warming has occurred over the past 100 years in the Vanderhoof area, with the 1990s being the warmest decade of the last century. Most of the warming is attributable to increases in mean daily minimum temperatures (with smaller or insignificant increases in daily maxima), which has resulted in a narrowing of the diurnal temperature range. Increases in T_{min} values have been seen in spring, summer, fall, and winter, but greater variability in winter T_{min} means fewer statistically significant differences for that season. Clear and consistent trends and patterns in average daily maximum temperatures and in seasonal precipitation are not evident.

From a forestry perspective, these climate trends have a number of potential implications. First, general warming, along with expected longer overall fire seasons, may have translated into increased fire risk and increased fire losses in the Vanderhoof area. Among other likely implications for forest management, the recent trends could eventually lead to more frequent and/or more intense droughts, which may cause increased mortality, reduced regeneration success, increased fire activity, and reduced timber growth and yield. Milder winters with shorter periods of freezing will reduce the period available for winter harvesting, but will also make the region's climate less suitable for the existing dominant species (pine and spruce) and more suitable for more southerly species such as Douglas-fir and western larch (*Larix occidentalis* Nutt.) (Hamann and Wang 2006). The biophysical responses of forests to future climate change are discussed in the section "Potential Impacts of Climate Change on Forests in the Study Area."

Table 8. Critical *t* values for comparisons of decadal average minimum spring temperatures for Vanderhoof[a]

	Decade									
Decade	1900–1909	1910–1919	1920–1929	1930–1939	1940–1949	1950–1959	1960–1969	1970–1979	1980–1989	1990–1999
1900–1909	X									
1910–1919	0.098	X								
1920–1929	−1.259	−1.221	X							
1930–1939	−1.391	−1.188	−0.631	X						
1940–1949	−1.959	−1.862	−0.949	−0.130	X					
1950–1959	−0.953	−0.777	0.018	0.641	0.792	X				
1960–1969	−1.841	−1.383	−1.125	−0.020	0.116	−0.861	X			
1970–1979	−2.511	−2.071	−2.362	−1.408	−0.892	−3.644	−1.392	X		
1980–1989	−3.815	−4.095	−5.073	−2.592	−2.326	−2.889	−3.310	−1.671	X	
1990–1999	−3.869	−4.176	−4.096	−2.803	−2.374	−3.890	−3.545	−2.650	−0.368	X

[a]Shaded cell indicates significant difference between the two means at the 95% confidence level (critical two-tailed *t* [9 df] = 2.262).

Table 9. Critical *t* values for comparisons of decadal average minimum summer temperatures for Vanderhoof[a]

	Decade									
Decade	1900–1909	1910–1919	1920–1929	1930–1939	1940–1949	1950–1959	1960–1969	1970–1979	1980–1989	1990–1999
1900–1909	X									
1910–1919	−1.674	X								
1920–1929	−2.471	−0.761	X							
1930–1939	−3.031	−1.687	−0.384	X						
1940–1949	−3.609	−3.149	−1.984	−2.343	X					
1950–1959	−4.420	−3.190	−2.222	−1.917	0.597	X				
1960–1969	−7.028	−4.922	−3.238	−3.873	−0.490	−0.863	X			
1970–1979	−5.542	−4.549	−3.041	−4.396	−2.116	−2.022	−1.346	X		
1980–1989	−6.926	−5.533	−4.393	−5.676	−3.210	−3.774	−2.995	−1.468	X	
1990–1999	−10.378	−9.561	−9.241	−9.280	−9.106	−9.872	−5.577	−3.716	−1.669	X

[a]Shaded cell indicates significant difference between the two means at the 95% confidence level (critical two-tailed t [9 df] = 2.262).

Table10. Critical *t* values for comparisons of decadal average minimum fall temperatures for Vanderhoof[a]

	Decade									
Decade	1900–1909	1910–1919	1920–1929	1930–1939	1940–1949	1950–1959	1960–1969	1970–1979	1980–1989	1990–1999
1900–1909	X									
1910–1919	1.068	X								
1920–1929	0.626	−0.085	X							
1930–1939	−0.675	−1.470	−1.757	X						
1940–1949	0.104	−0.582	−0.546	0.757	X					
1950–1959	−0.077	−0.998	−0.679	0.599	−0.154	X				
1960–1969	−0.766	−1.706	−1.666	−0.295	−0.870	−0.619	X			
1970–1979	−1.723	−1.882	−1.934	−0.628	−0.998	−0.913	−0.408	X		
1980–1989	−0.899	−1.394	−1.425	−0.479	−1.248	−0.900	−0.312	0.085	X	
1990–1999	−2.900	−4.483	−4.489	−2.125	−2.626	−2.142	−2.451	−1.245	−1.070	X

[a]Shaded cell indicates significant difference between the two means at the 95% confidence level (critical two-tailed t [9 df] = 2.262).

Table 11. Critical t values for comparisons of decadal average minimum winter temperatures for Vanderhoof[a]

	Decade									
Decade	1900–1909	1910–1919	1920–1929	1930–1939	1940–1949	1950–1959	1960–1969	1970–1979	1980–1989	1990–1999
1900–1909	X									
1910–1919	0.364	X								
1920–1929	−0.473	−0.740	X							
1930–1939	−0.514	−1.194	0.110	X						
1940–1949	−0.550	−0.770	0.170	0.058	X					
1950–1959	−0.556	−1.075	0.003	−0.237	−0.153	X				
1960–1969	−0.630	−0.865	−0.026	−0.154	−0.231	−0.032	X			
1970–1979	−0.611	−0.916	−0.267	−0.297	−0.372	−0.180	−0.204	X		
1980–1989	−2.326	−2.657	−1.663	−2.019	−2.023	−1.783	−3.194	−2.227	X	
1990–1999	−1.924	−2.301	−1.590	−3.050	−1.645	−2.048	−1.165	−1.356	0.030	X

[a]Shaded cell indicates significant difference between the two means at the 95% confidence level (critical two-tailed t [9 df] = 2.262).

The observed increases in T_{min} values, particularly since 1990, are probably one important contributing factor in the MPB outbreak; periods of extreme cold result in beetle mortality, and hence, the reduced frequency of cold winters has likely contributed to population expansion (Carroll et al. 2004; Logan and Powell 2004). However, it must be recognized that insect population explosions result from a wide range of complex interacting causes. In the case of MPB in the pine forests of interior British Columbia, these factors may include drought (which increases tree stress and susceptibility to attack), changes in insect life-cycle phenology, large fires in the early part of the 20th century leading to widespread distribution of continuous stands of lodgepole pine, stronger fire-suppression policies, and, in time, a generally mature forest (Taylor et al. 2006).

Climate change is often dismissed as a future issue with little importance today. However, this analysis suggests that the climate of the Vanderhoof region has already changed significantly, within the past 30–50 years. Aside from the likely role of this warming in the MPB outbreak, other impacts may have occurred. Residents have reported landscape changes that could be at least partly related to climate change. Such observations provide important information to complement scientific data collection and analysis.

Future Climate Scenarios

Methodology

Simulation results from three general circulation models (GCMs, also referred to as global climate models) were used to develop the Vanderhoof climate scenarios for this study: the Canadian Second-Generation Coupled Global Climate Model (CGCM2), using data obtained from the Canadian Climate Centre for Modeling and Analysis (http://www.cccma.bc.ec.gc.ca); the Hadley Centre Third-Generation Coupled Model (HadCM3, developed by the UK Hadley Centre; http://www.metoffice.com/research/hadleycentre/index.html), using data obtained from the Intergovernmental Panel on Climate Change (IPCC) Data Distribution Centre (http://ipcc-ddc.cru.uea.ac.uk/); and the Commonwealth Scientific and Industrial Research Organization (CSIRO) Mark 2 model (CSIRO Mk2), developed by the CSIRO's Atmospheric Research Laboratory (http://www.csiro.au).[3]

For each model, two different but widely recognized greenhouse gas (GHG) emissions scenarios (A2 and B2) were considered. The IPCC instigated a series of projections of global population growth and economic development, encapsulated in the *Special Report on Emissions Scenarios* (SRES; Nakćenović and Swart 2000). The various projections encompass several "families" of projections ("scenarios") based on different assumptions about the global future, of which two were selected. The first of these is the relatively pessimistic A2 scenario, which assumes a rate of increase in GHG emissions comparable to the rate of increase in the 1990s. In the more optimistic B2 scenario, societies are more socially and environmentally conscious, with slower population growth, lower energy intensity, and less reliance on fossil fuels, which leads to much lower growth in GHGs. The key difference is in the assumed increase in atmospheric carbon dioxide (CO_2) concentration by 2100: the A2 scenario assumes an increase to about 820 parts per million by volume (ppm), whereas the B2 scenario assumes an increase to 605 ppm. For the sake of comparison, present-day (December 2007) levels are about 385 ppm and the preindustrial (around 1860) was about 280 ppm.

The SRES emissions scenarios have been used by the various global climate modeling groups to "force" their respective models. It was therefore possible to select the results of simulations obtained from each of the three GCMs named above for each of the A2 and B2 scenarios, yielding a set of six scenarios of future climate that could be investigated for the Vanderhoof study area.

A major concern in the use of any GCM scenario of future climate is that the model may be biased relative to present-day reality; in other words, the average temperature (or any

[3]At the time of this study, only the results of the CSIRO Mark 2 GCM were available. The current version of the model is CSIRO Mark 3.5. For further information, refer to the following link: http://www-pcmdi.llnl.gov/ipcc/model_documentation/CSIRO-Mk3.5.htm.

other climate variable) computed by the GCM for a specific location or region on the planet for a historical period, such as 1951–2000, will probably be significantly higher or lower than the average of observed measurements for that location or region during the defined period. This implies that GCM forecasts of future climate, in terms of the absolute values of climate variables for a specific location, are also likely to be biased. The reasons for local bias are complex, but at global or continental scales, GCMs typically simulate spatial averages that are consistent with observations.

For this study, a practical, commonly used solution to the potential problem of bias was adopted. For each scenario the original monthly data simulated by each GCM for each variable were converted to differences from the means simulated by the models for the 1961–1990 period. This involved first calculating the 30-year averages of the climate values for each month in the period 1961–1990 as simulated by each model and then calculating temperature changes by subtracting these mean values for each month from the simulated values for the same month in the period 2001–2100. These differences are termed "pseudo-anomalies." In the case of precipitation, solar radiation, wind speed, and humidity, the monthly values were divided by the means, rather than being subtracted from them, because these variables are all measured on a scale from zero to some maximum. Temperature is treated differently because its true (absolute) zero is at −273.16 ºC; hence, for the range of temperatures experienced in day-to-day weather, it is more practical to calculate changes on a linear scale.

Monthly pseudo-anomalies were computed for each grid point in the GCM spatial coverage for North America using the 1961–1990 means as the baseline. The spatial resolution of GCMs is low, with a typical horizontal distance of 300–400 km between grid points. This means that a region the size of North America is represented by a map containing perhaps only 200 points (compared to the several thousand climate stations used to observe real weather patterns). Given this poor spatial resolution, the GCMs also have very limited representation of the effects of surface topography (mountains, plains, and oceans) on simulated weather patterns. This is a major cause of regional bias, and a potential cause of uncertainty in interpreting climate scenarios derived from GCM simulations. For these reasons, the pseudo-anomalies were interpolated to the same 10-km grid as the historical climate data, but only on the basis of horizontal distance, without taking elevation effects into account (see Price et al. 2004; McKenney et al. 2006). The final scenarios were created by combining the interpolated 1961–1990 normals (based on observed data) with the interpolated pseudo-anomalies (by adding simulated temperature differences to the observed means and by multiplying simulated ratios by the observed means for other climate variables). In this way, the scenario results were all brought to a common base representative of the Vanderhoof study area. Changes in climate were expressed for each point location relative to the observed 1961–1990 averages. Each climate scenario therefore combines the observed spatial variability in climate for and across the study area with the long-term "warming signal" obtained from each GCM, as forced by a specific GHG emissions scenario.

Scenarios of Future Climate for the Vanderhoof Study Area

As described in the previous section, the historical climate data compiled for the Vanderhoof region were aggregated into spatial means (averaged for all 10-km grid cells inside the rectangular study region). A similar approach was used to compare historical observations with the climate scenario data. However, only the trends in 20-year averages for each GCM and emission scenario combination are provided (see Figures 15 and 16).

Figure 15 shows historical and six possible future temperature trends (based on the six GCM and emission scenario combinations), averaged over 20-year periods. For the six temperature projections, the differences among the three GCMs were much greater than the differences between the different GHG emissions scenarios. On the basis of these results, the three GCMs were classified as "hot" (CSIRO Mk2), "warm" (CGCM2), and "cool" (HadCM3), to reflect the projected range of increases in temperature.

The assumptions built into each GCM represent a substantial source of uncertainty. Nevertheless, the results across GCMs are consistent in suggesting that future average daily minimum temperatures are likely to increase more than future average daily maximum temperatures, with expected increases of approximately 1.5 ºC to 6.0 ºC for the minima and 1.0 ºC to 4.0 ºC for the maxima projected over the 21st century. These projections are also consistent with other reports of GCM temperature scenarios (e.g., Houghton et al. 2001), which suggest that globally, and particularly in midcontinental regions, average temperatures will increase more in winter than in summer.

Projected trends in precipitation are much less clear, with the CGCM2 and HadCM3 models overlapping and showing no clear increase over the long term (Figure 16). In contrast, the CSIRO Mk2 projects increases in average annual rainfall of about 100 mm, which represents an increase on the order of 20% over present-day amounts. Rainfall varies greatly from year to year (and from place to place), to a much greater extent than does temperature, but the trend lines in Figure 16 hide all of this variability. In reality, even if rainfall were to increase by 20% on average, the change might not be perceptible, particularly after the greater losses in evaporation resulting from generally warmer temperatures are taken into account. Nevertheless, on the basis of these results, the three models were classified as as "wet" (CSIRO Mk2) or "dry" (CGCM2 and HadCM3).

The historical trend in precipitation (Figure 16) is of interest because it allows an assessment of the general quality of the reconstructed precipitation record. Before 1950, the station coverage across Canada was sparser and data quality generally poorer. It is possible, therefore, that measurements made in the first half of the 20th century underestimate true annual precipitation, particularly in more rural areas such as central British Columbia. However, the marked decline in precipitation observed for the period 1921–1940 is consistent with the serious drought of the 1930s, while the higher annual totals for 1901–1920 are comparable to the more recent data for 1941–1980. This indicates that poor data quality did *not* cause precipitation to be systematically underestimated in the early 20th century.

The climate data were also used to generate climate maps for the past, the present day, and two periods in the future (Figures 17–20). For these maps to be meaningful and comparable, it was necessary to average several years of data (as is the practice for computing climate normals). A 10-year averaging period was adopted for the data presented in Figures 17 to 20. Averages of the key climate variables for four 10-year periods were centered on a specific year (1905 as the central year for the period 1901–1910, 1995 for 1991–2000, 2045 for 2041–2050, and 2095 for 2091–2100). To compare winter and summer conditions, the data shown in each map are mean daily minimum temperature or total precipitation computed for 3 months: June to August for summer results and December to February for winter data. To reduce complexity these maps were limited to one scenario per GCM. Given that the HadCM3 model projects the smallest increases in temperature, results for this model are provided for the optimistic B2 emissions scenario. This can be considered to represent the smallest predicted change in climate. Results are also provided for the more pessimistic A2 scenario for the CSIRO Mk2 and the CGCM2 models. These models show larger changes, but they differ in terms of the relative amounts of warming and the projected precipitation change.

It is important to reiterate that the future projections represented by Figures 17 to 20 should all be interpreted with caution. They should not be regarded as predictions, but rather as scenarios of possible outcomes. From the present-day perspective, it must be assumed that all six scenarios of future climate are equally plausible.

Figures 17 and 18 confirm that the region was appreciably warmer at the end of the 20th century than at the beginning of the century. Summer minimum temperatures appear to have increased quite uniformly over the region, but are perhaps 2 ºC cooler in the south and west, on average, than elsewhere (Figure 17). Conversely, winter minimum temperatures increased less

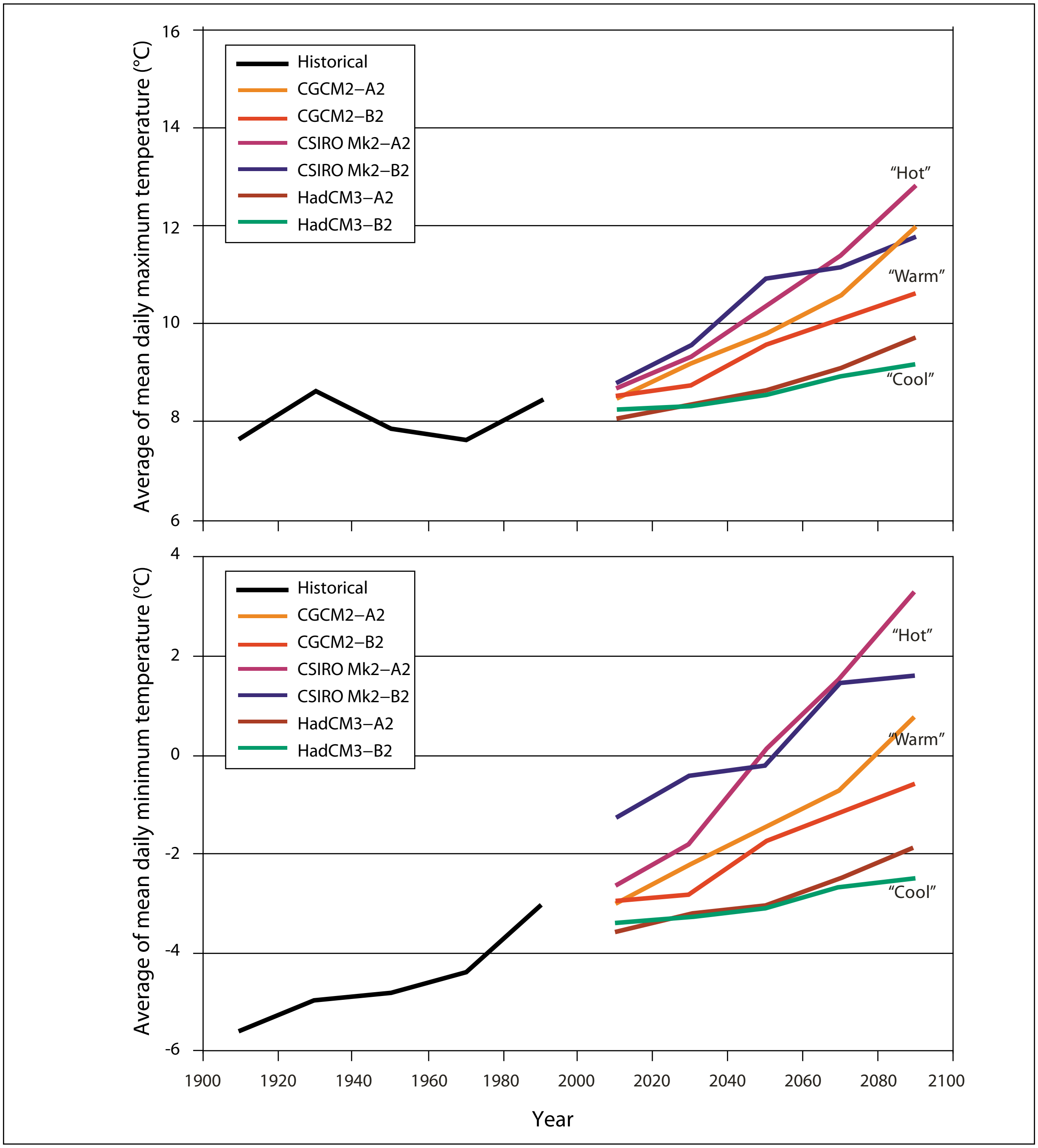


Figure 15. Historical and possible future trends in annual mean daily minimum and maximum temperatures in the Vanderhoof region, 1901–2100. Mean daily minimum and maximum temperatures were calculated annually for each weather station in the area; these station means were then averaged to generate the overall mean for each year. Each data point is averaged from 20 years of monthly values and spatially averaged over 350 grid cells (covering the 200-km rectangle surrounding Vanderhoof). Hence the lines show only the general trends and do not show much year-to-year variation. Historical data (up to 2000) have been interpolated from available climate station records. Future projections (from 2001 onward) were taken from six different general circulation model simulations. CGCM2 = Canadian Second-Generation Coupled Global Climate Model; CSIRO Mk2 = Commonwealth Scientific and Industrial Research Organization Mark 2 model; HadCM3 = Hadley Centre Third-Generation Coupled Model; A2 = scenario with a regionalized global economy in which the rate of increase in greenhouse gas emissions is comparable to the rate of increase in the 1990s; B2 = scenario with a regionalized global economy in which societies are more socially and environmentally conscious than in scenario A2, with slower population growth, lower energy intensity, and less reliance on fossil fuels, leading to a much lower rate of growth in greenhouse gas emissions.

uniformly, with the most dramatic increases (perhaps as large as 10 ºC) occurring at the eastern edge of the region (Figure 18). Even if these extremes are artifacts of the interpolation procedure, the spatial averages clearly show some significant increases in winter minima in recent decades.

For the future, the three GCM simulations projected further increases in minimum temperatures for both summer and winter. The spatial distributions seen in the 1991–2000 decadal maps recurred for the 2040s and 2090s, because the changes projected in each GCM scenario were superimposed on the baseline climate observed for 1961–1990. The HadCM3 model, forced by the B2 emissions scenario, projected the smallest increases, while the CGCM2 and CSIRO Mk2 models projected progressively greater increases. Compared with 1995, the CSIRO Mk2 model projected increases in the east and northwest of the region of about 5 ºC in summer and as much as 10 ºC in winter by 2095. Although these might seem to be major changes, they are quite plausible, given the evidence of significant warming since 1900.

With respect to precipitation, the maps in Figures 19 and 20 show two trends. First, the 1990s were significantly drier on average than

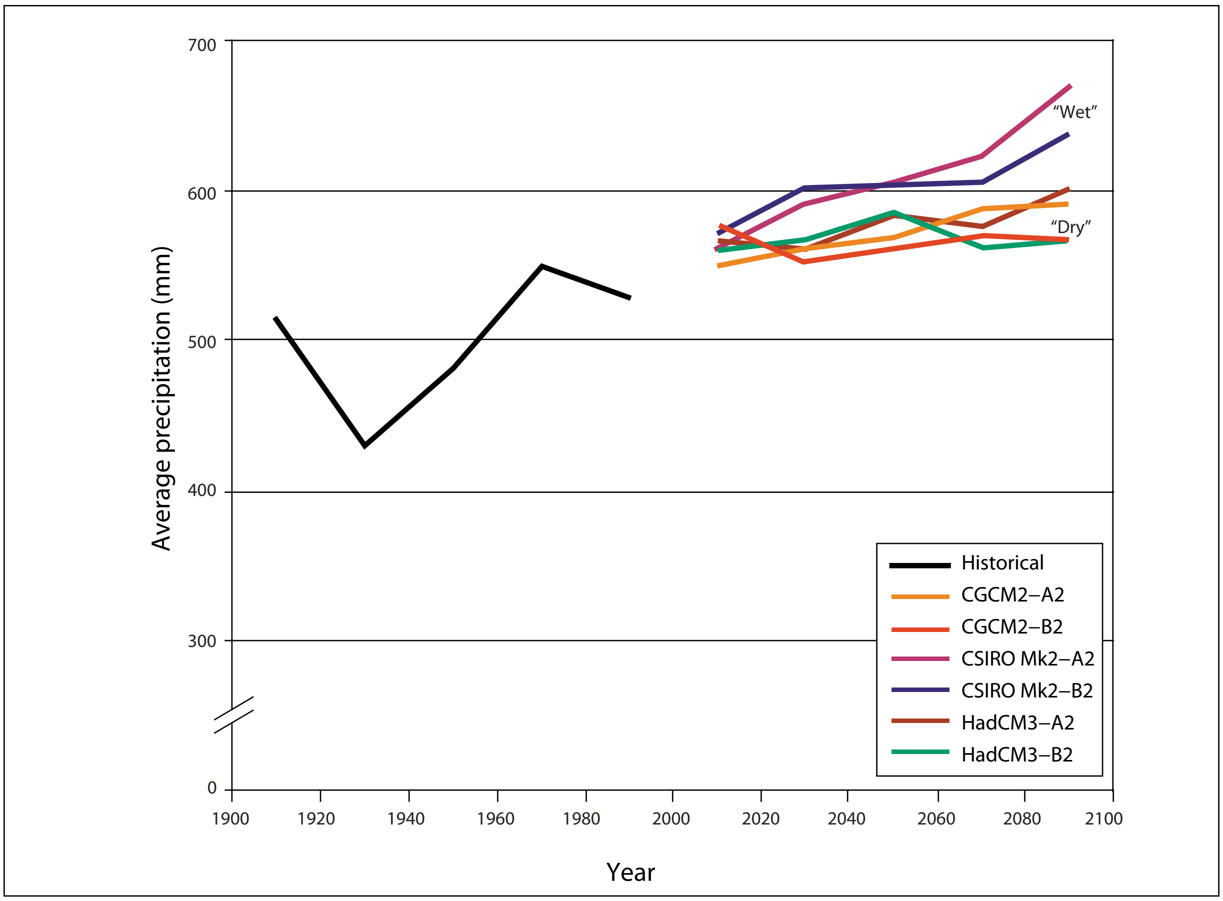


Figure 16. Historical and possible future trends in annual precipitation in the Vanderhoof region, 1901–2100. Each data point is averaged from 20 years of monthly values and spatially averaged over 350 grid cells (covering the 200-km rectangle surrounding Vanderhoof). Hence the lines show only the general trends and do not show much year-to-year variation. Historical data (up to 2000) have been interpolated from available climate station records. Future projections (from 2001 onward) were taken from six different general circulation model simulations. CGCM2 = Canadian Second-Generation Coupled Global Climate Model; CSIRO Mk2 = Commonwealth Scientific and Industrial Research Organization Mark 2 model; HadCM3 = Hadley Centre Third-Generation Coupled Model; A2 = scenario with a regionalized global economy in which the rate of increase in greenhouse gas emissions is comparable to the rate of increase in the 1990s; B2 = scenario with a regionalized global economy in which societies are more socially and environmentally conscious than in scenario A2, with slower population growth, lower energy intensity, and less reliance on fossil fuels, leading to a much lower rate of growth in greenhouse gas emissions.

the first decade of the 20th century. Second, the spatial distribution has evidently changed, with greatest precipitation occurring in the west and southwestern corner around 1905 but in the northwestern corner by 1995, and the southwest becoming the driest area by that time. This trend was observed for both summer and winter, with dramatic reductions in winter rainfall noticeable in the south. It is impossible to verify that these changes are real, as improvements in station coverage and/or measurement quality may have contributed to apparent changes in precipitation during the 20th century.

The various precipitation projections generated by the GCMs generally show this regional shift. All of the models projected increases in annual precipitation, the smallest with HadCM3 (combined with the B2 emissions scenario) and the largest with the CSIRO Mk2 (combined with the A2 emissions scenario). The models were also consistent in predicting that the greatest precipitation increases would occur in summer.

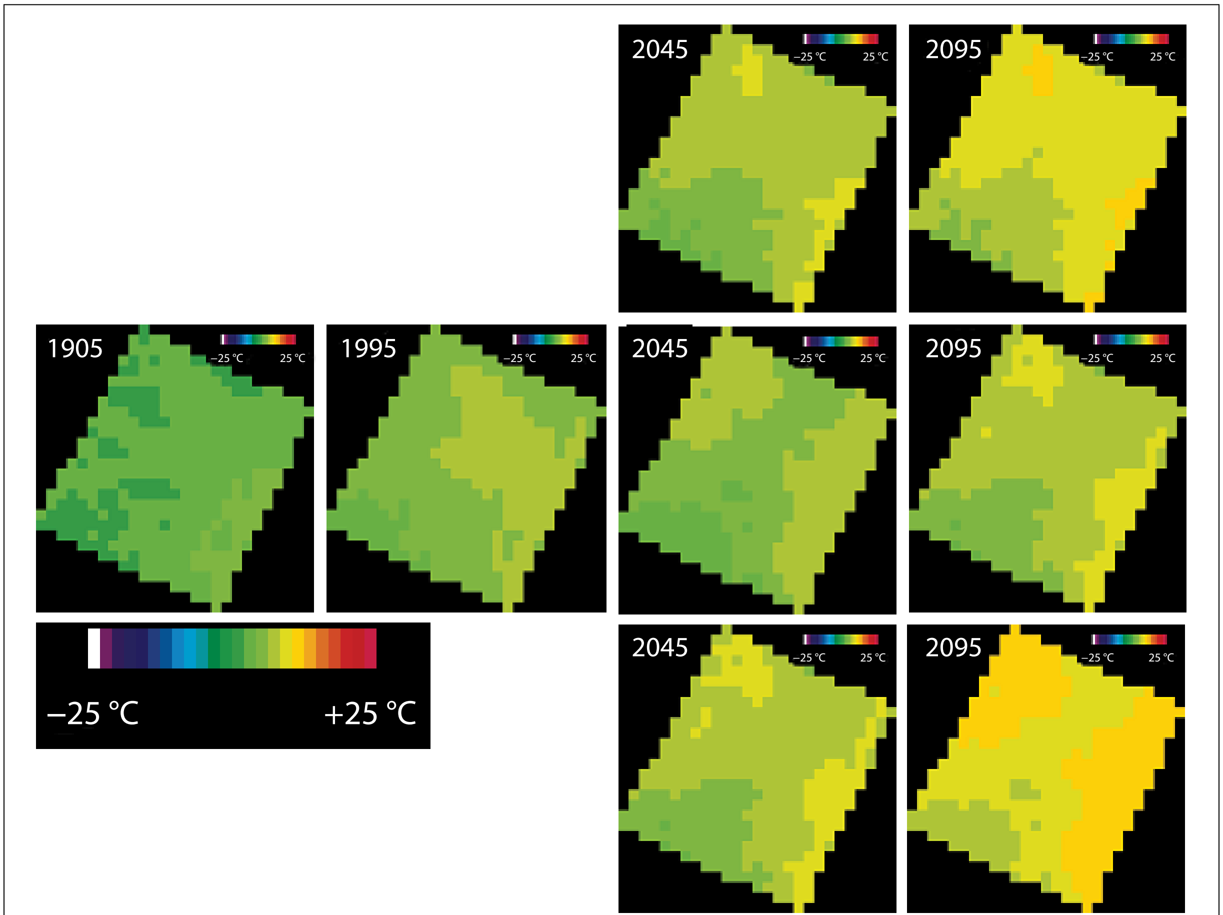


Figure 17. Historical changes and projections of future summer temperatures in the Vanderhoof region, 1901–2100. Each displayed rectangle measures approximately 200 km on each side, with the town of Vanderhoof at its center. Each map is based on monthly mean data for June, July, and August and averaged over a 10-year period (centered on the indicated year). Historical maps (left side) have been interpolated from available climate station records. Future projections (right side) were taken from three different general circulation model simulations, as follows: top: Canadian Second-Generation Coupled Global Climate Model, forced by A2 emissions scenario ("warm, dry"); center: Hadley Centre Third-Generation Coupled Model, forced by B2 emissions scenario ("cool, dry"); bottom: Commonwealth Scientific and Industrial Research Organization Mark 2 model, forced by A2 emissions scenario ("hot, wet"). A2 = scenario with a regionalized global economy in which the rate of increase in greenhouse gas emissions is comparable to the rate of increase in the 1990s. B2 = scenario with a regionalized global economy in which societies are more socially and environmentally conscious than in scenario A2, with slower population growth, lower energy intensity, and less reliance on fossil fuels, leading to a much lower rate of growth in greenhouse gas emissions.

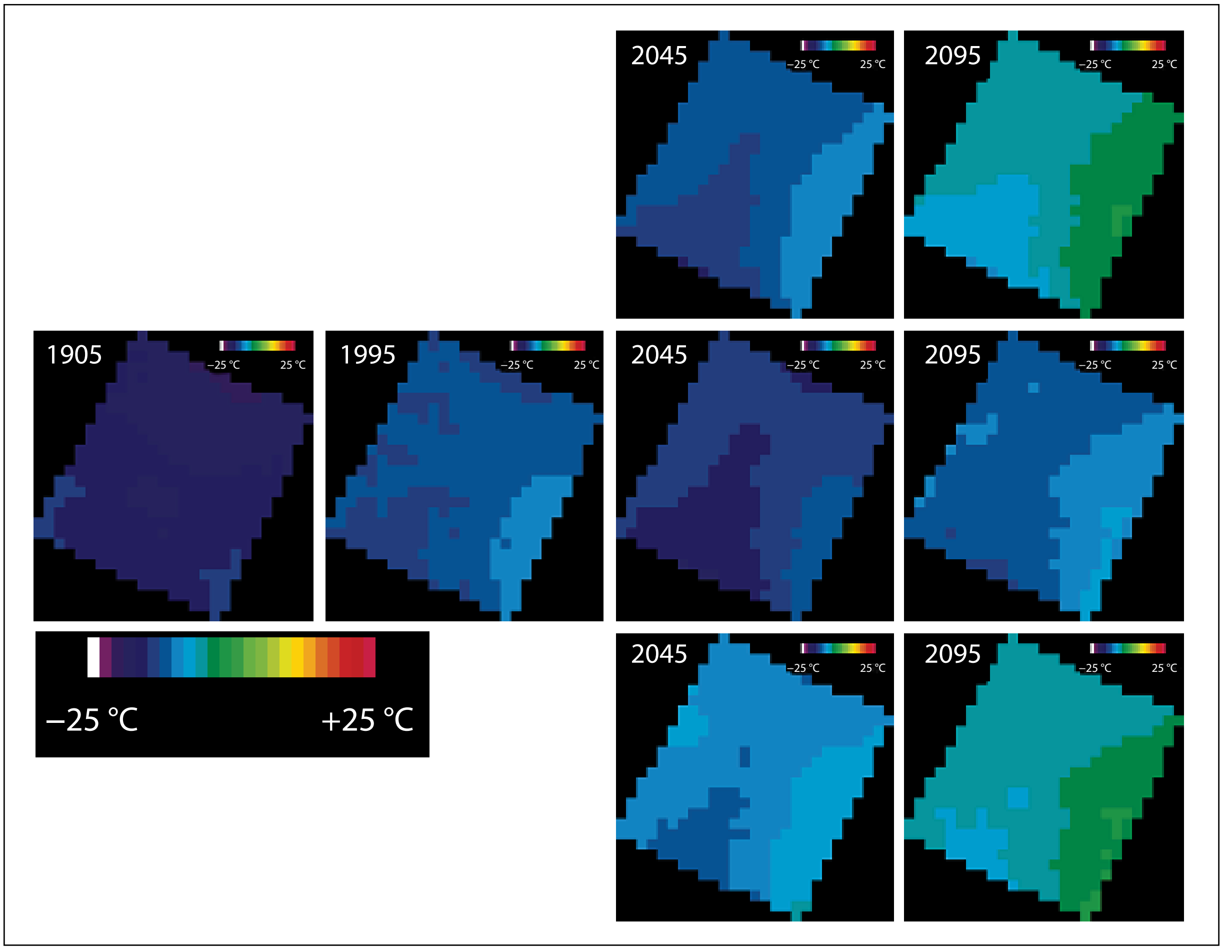


Figure 18. Historical changes and projections of future winter temperatures in the Vanderhoof region, 1901–2100. Each displayed rectangle measures approximately 200 km on each side, with the town of Vanderhoof at its center. Each map is based on monthly mean data for December, January, and February and averaged over a 10-year period (centered on the indicated year). Historical maps (left side) have been interpolated from available climate station records. Future projections (right side) were taken from three different general circulation model simulations, as follows: top: Canadian Second-Generation Coupled Global Climate Model, forced by A2 emissions scenario ("warm, dry"); center: Hadley Centre Third-Generation Coupled Model, forced by B2 emissions scenario ("cool, dry"); bottom: Commonwealth Scientific and Industrial Research Organization Mark 2 model, forced by A2 emissions scenario ("hot, wet"). A2 = scenario with a regionalized global economy in which the rate of increase in greenhouse gas emissions is comparable to the rate of increase in the 1990s. B2 = scenario with a regionalized global economy in which societies are more socially and environmentally conscious than in scenario A2, with slower population growth, lower energy intensity, and less reliance on fossil fuels, leading to a much lower rate of growth in greenhouse gas emissions.

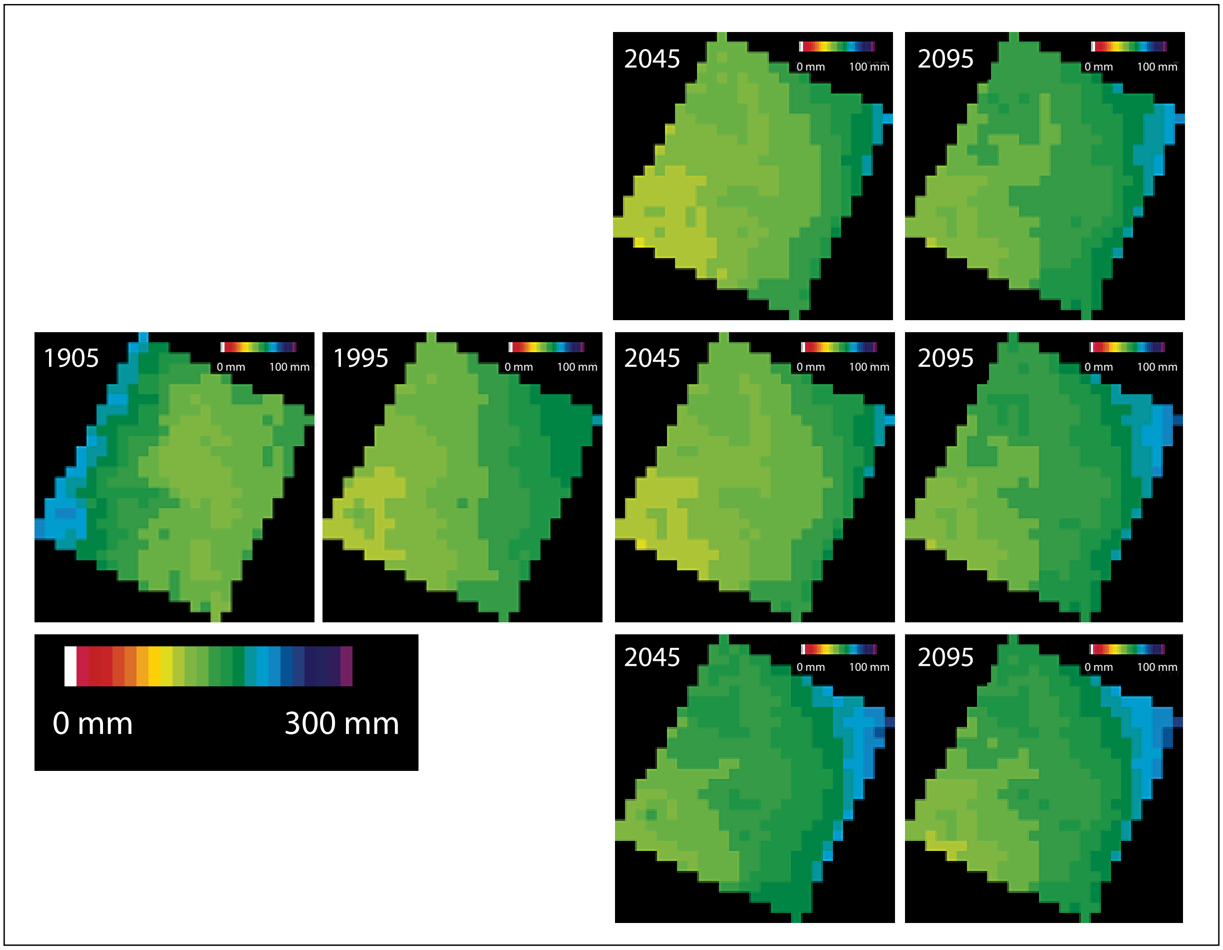


Figure 19. Historical changes and projections of future summer precipitation (rain plus snow) in the Vanderhoof region, 1901–2100. Each displayed rectangle measures approximately 200 km on each side, with the town of Vanderhoof at its center. Each map is based on data summed for June, July, and August and averaged over a 10-year period (centered on the indicated year). Historical maps (left side) have been interpolated from available climate station records. Future projections (right side) were taken from three different general circulation model simulations, as follows: top: Canadian Second-Generation Coupled Global Climate Model, forced by A2 emissions scenario ("warm, dry"); center: Hadley Centre Third-Generation Coupled Model, forced by B2 emissions scenario ("cool, dry"); bottom: Commonwealth Scientific and Industrial Research Organization Mark 2 model, forced by A2 emissions scenario ("hot, wet"). A2 = scenario with a regionalized global economy in which the rate of increase in greenhouse gas emissions is comparable to the rate of increase in the 1990s. B2 = scenario with a regionalized global economy in which societies are more socially and environmentally conscious than in scenario A2, with slower population growth, lower energy intensity, and less reliance on fossil fuels, leading to a much lower rate of growth in greenhouse gas emissions.

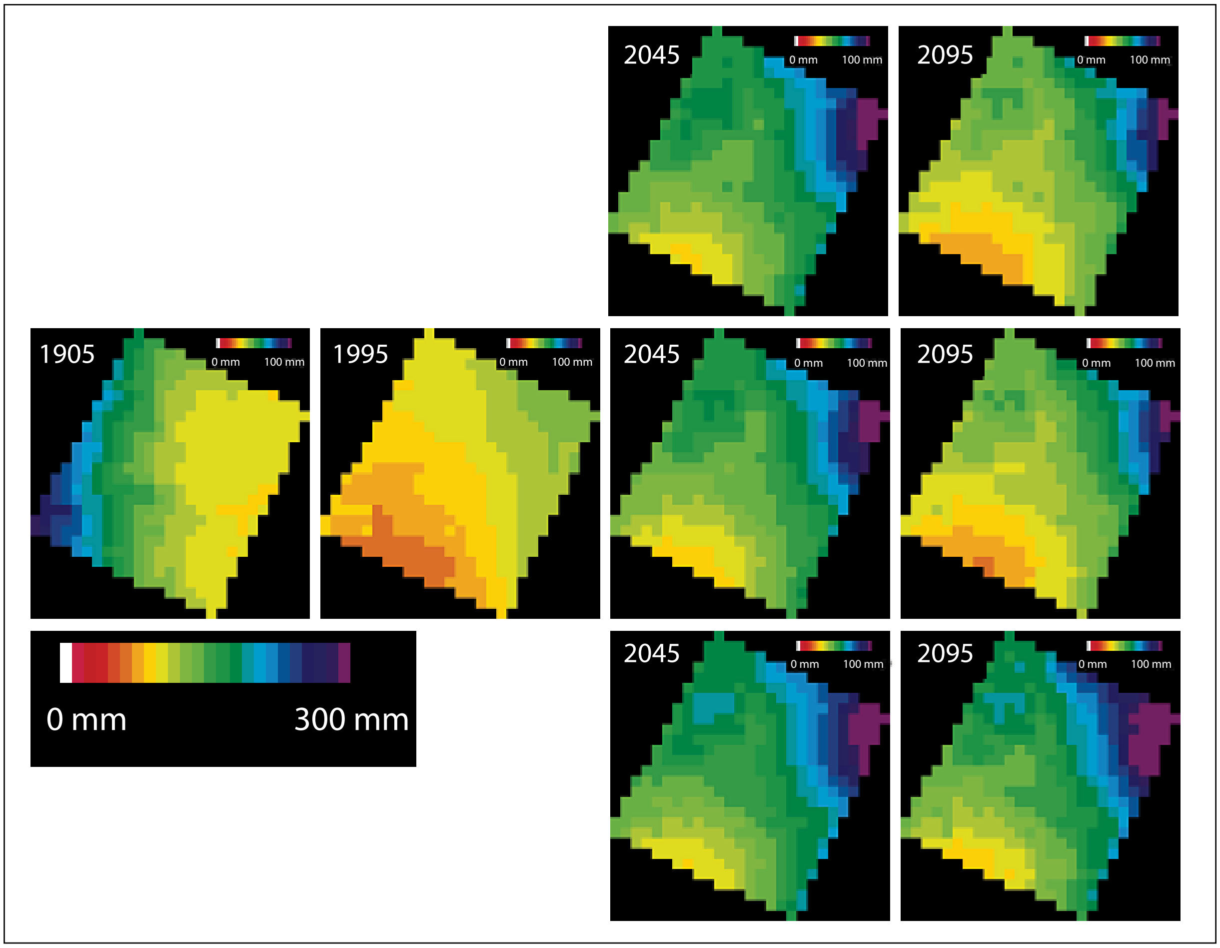


Figure 20. Historical changes and projections of future winter precipitation (rain plus snow) in the Vanderhoof region, 1901–2100. Each displayed rectangle measures approximately 200 km on each side, with the town of Vanderhoof at its center. Each map is based on data summed for December, January, and February and averaged over a 10-year period (centered on the indicated year). Historical maps (left side) have been interpolated from available climate station records. Future projections (right side) were taken from three different general circulation model simulations, as follows: top: Canadian Second-Generation Coupled Global Climate Model, forced by A2 emissions scenario ("warm, dry"); center: Hadley Centre Third-Generation Coupled Model, forced by B2 emissions scenario ("cool, dry"); bottom: Commonwealth Scientific and Industrial Research Organization Mark 2 model, forced by A2 emissions scenario ("hot, wet"). A2 = scenario with a regionalized global economy in which the rate of increase in greenhouse gas emissions is comparable to the rate of increase in the 1990s. B2 = scenario with a regionalized global economy in which societies are more socially and environmentally conscious than in scenario A2, with slower population growth, lower energy intensity, and less reliance on fossil fuels, leading to a much lower rate of growth in greenhouse gas emissions.

POTENTIAL IMPACTS OF FUTURE CLIMATE CHANGE ON FORESTS IN THE STUDY AREA

Climate change may affect forests in a number of ways. First, it may alter competitive interrelationships between species, resulting in a change in forest composition. Second, it may increase the regeneration success of some species while reducing the success of other species. Third, it may increase or decrease productivity and growth, depending on species composition and location. Finally, it may affect patterns of disturbance (e.g., fire, insects, and disease) (Flannigan and Van Wagner 1991; Volney and Hirsch 2005). Thus, both forest composition and forest ecosystem processes are likely to be affected by future changes in the climate. However, the magnitude and timing of these changes will vary considerably from one location to another depending on local sensitivity of the forest ecosystem to changes in climate and the way that climate change is expressed at a particular location. This section describes and illustrates the development of methodologies for assessing how future climate change will affect forest ecosystems in the Vanderhoof study area. The section has two main components. First a model is described for assessing changes in forest composition, standing inventory, and primary productivity under the various climate scenarios described in the previous section. This model has been applied to the Vanderhoof study area, and the results of that analysis are presented. The second component introduces a model for and describes considerations in assessing the impact of climate change on the susceptibility of forests to forest fire and presents an approach to doing such an assessment. This model was also applied to the Vanderhoof study area, and the results of the analysis are presented.

Forest Ecosystem Composition and Productivity

Objectives

The projections of future climate reported in the previous section provide a set of "tinted windows on the future." Each tint superimposes on today's climate a slightly different picture of what is known (e.g., about how the atmosphere will change with increased concentrations of GHGs) and hence allows examination of a range of possible future climates. Importantly, none of these future climates can be considered more likely than any other. All of them will prove incorrect in some way, but they should be considered "equally plausible" in the absence of more certain knowledge. The climate scenario data were used to drive a Canadian version of a dynamic vegetation model of ecosystem processes called the Integrated Biosphere Simulator (IBIS), first developed at the University of Wisconsin in Madison (Foley et al. 1996; Kucharik et al. 2000; El Maayar et al. 2001, 2002).

This part of the study had the following objectives:

- to test and calibrate a dynamic vegetation model (the Canadian Integrated Biosphere Simulator [Can-IBIS]) with historical climate data for the Vanderhoof study area to see how well it reproduces the present-day forest cover (using a small set of diagnostic outputs that can be compared with observations or measured data)
- to use the future climate scenarios described above to drive the calibrated vegetation model as a means of exploring the range of possible impacts that these scenarios will have on forests in the study area
- to generate estimates of changes in forest composition and productivity (in terms of species composition, annual wood production, and standing volume) for incorporation into an analysis of the economic impacts resulting from changes in local timber supply (see the section entitled "Potential Impacts of Climate Change on the Local Economy")

Description of the Canadian Integrated Biosphere Simulator

In common with many other ecosystem process models, the Canadian Integrated Biosphere Simulator (Can-IBIS) performs spatial simulations by operating on a common "grid" of many data layers. It requires data for several monthly climate variables, including mean daily maximum and minimum temperatures, precipitation, solar radiation, atmospheric humidity, and wind speed, together with some derived variables, such as the difference between the mean temperature of the coldest month (assumed to be January) and the coldest recorded temperature. The model uses the climate data to drive an internal "weather generator," which in turn uses statistical relationships to convert monthly climate statistics into hourly values. The model also requires information on soil texture and depth and grid-cell data for mean elevation and slope angle (taken from a digital elevation map).

As explained in the preceding section ("The Climate of the Vanderhoof Study Area"), climatological data were interpolated from local station records, and from GCM scenario data. Soil physical characteristics were derived from data in the Canadian Soil Information System (CanSIS, version 2.2) (available at http://sis.agr.gc.ca/cansis/ accessed 15 April 2008). These data are known to be only approximate, particularly for forested areas where coverage by soil surveys is relatively poor. However, a recent development within Can-IBIS, adopted for the Vanderhoof simulations, explicitly accounts for the distribution of different soil types within each grid cell. With this approach, soil characteristics are not spatially averaged; instead, as many as five dominant soil types are used to drive independent simulations of vegetation responses, which are then averaged according to the fractional area of the grid cell occupied by each soil type.

The detailed structure and functioning of IBIS are reported elsewhere (Foley et al. 1996; Kucharik et al. 2000; El Maayar et al. 2001, 2002), but the modifications specific to Can-IBIS have yet to be reported in detail. As illustrated and described in Figure 21, the model attempts to represent how vegetation processes at all scales (from the level of individual leaves up to the landscape level) are affected by and interact with the physical and chemical environment, including climate, atmospheric CO_2 concentration, and soil factors such as water-holding capacity and nitrogen (N) availability.

Vegetation is simulated as a combination of plant functional types (PFTs; see Figure 21), each PFT having a set of ecophysiological parameters that represent characteristic differences in rates of photosynthesis and respiration; specific leaf area (the ratio of leaf area to leaf mass); allocation of carbohydrate to stems, leaves, and roots; and tolerances for water and nutrient stresses. PFTs are broad conceptual groupings of dominant plant species that characterize different biomes (hence allowing the model to represent global vegetation distribution with a relatively small number of "species"). The original version of IBIS has 12 PFTs, but Can-IBIS has 15 PFTs, to allow Canadian vegetation types to be represented with more precision: 10 tree PFTs (4 boreal, 3 temperate, and 3 tropical types, of which the latter never appeared in the Vanderhoof simulations), 2 shrub PFTs, 2 grass PFTs, and 1 moss PFT.

Can-IBIS operates on an hourly time step. Grid-cell water balance is updated for every time step, with precipitation input (minus intercepted water) balanced against canopy evapotranspiration, drainage, and surface runoff. Low soil water content reduces photosynthetic capacity and hence limits PFT growth, with different PFTs being more or less susceptible. Hourly photosynthesis and respiration for each PFT are calculated as functions of incoming radiation, temperature, humidity, soil water content, CO_2, and simulated leaf area and are used to estimate net primary production (NPP). For each simulated day, estimated NPP is then allocated to leaves, stemwood, and fine roots. Soil microbial decomposition and N cycling are also simulated for each day, and the various soil carbon pools are then updated. At the end of every simulated year, a portion of each carbon pool is discarded as plant litter or is released to the atmosphere. Losses due to simulated disturbances are also tracked, with transfers to litter and the atmosphere. Simulated litter production is decomposed according to a daily time step over the following year to add carbon to the soil organic carbon pools or to release additional CO_2.

A phenology algorithm tracks daily temperature data to determine when leaves first

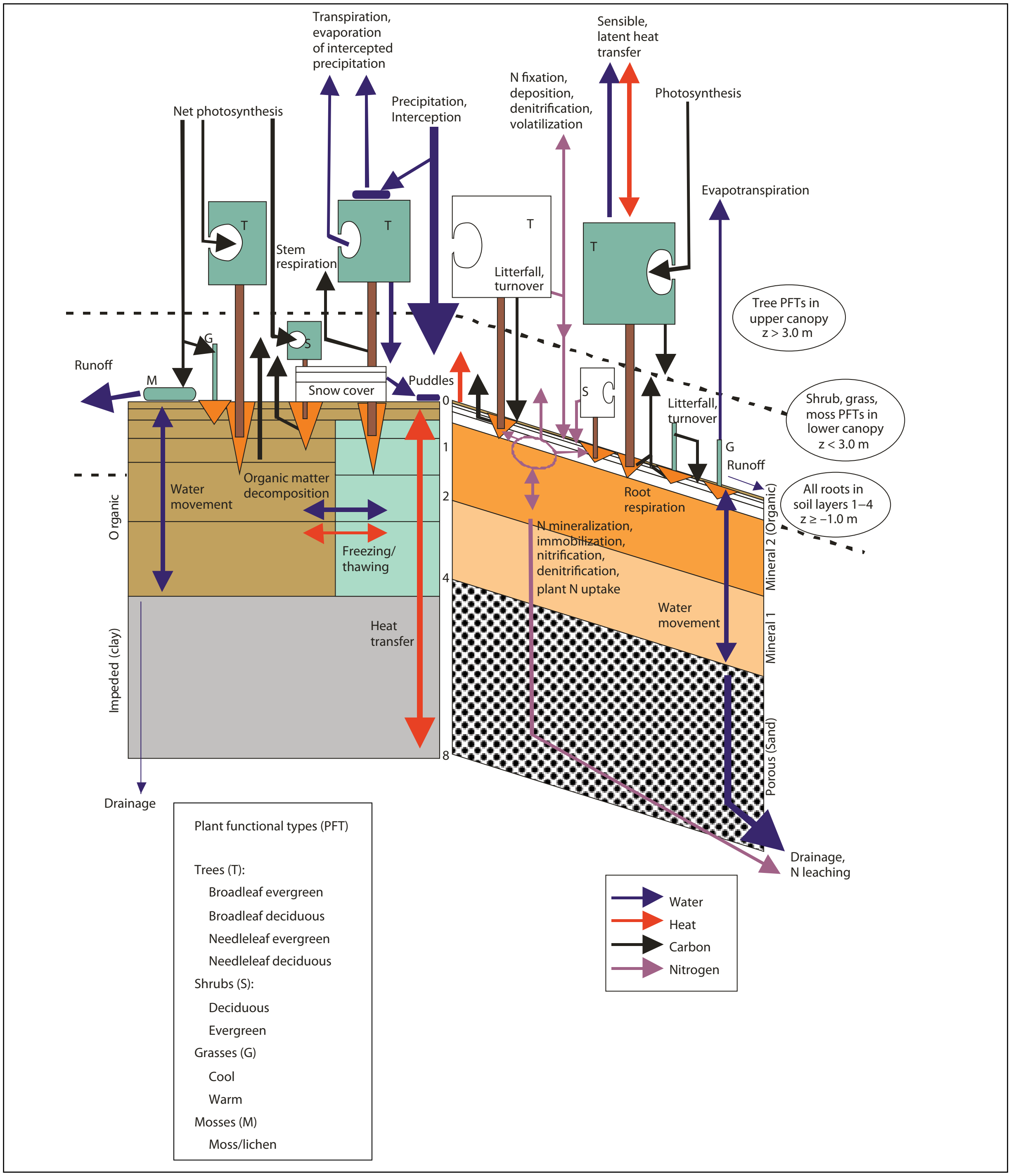


Figure 21. Schematic diagram of the Canadian Integrated Biosphere Simulator dynamic vegetation model (adapted from Foley et al. [1996], with extensive modifications). Vegetation is represented as a mixture of "plant functional types" (PFTs), each of which simulates a group of broadly similar types of trees, shrubs, and herbs found in ecosystems across North America. Each PFT has a unique combination of factors representing its morphology, growth physiology, and ecological processes. The model allows a mixture of PFTs to grow, compete, and die in response to the climate, topography, soil conditions, and disturbance regime (fires) occurring at a geographic location. It then tracks the flows of water, nutrients, and energy within the simulated ecosystem, which may contribute to further changes in environmental factors such as temperature and soil water content. In the application to the Vanderhoof study area, the model assumes that all processes occur uniformly in 10-km square grid cells. Each grid cell is completely independent of its neighbors. N = nitrogen, z = height or depth.

appear on deciduous PFTs and when grasses and mosses turn green. A separate algorithm uses daily temperature data to kill off nonhardy PFTs (e.g., those that cannot survive a hard frost).

The model makes no initial assumptions about the range of stand ages. Instead, Can-IBIS creates an approximate age-class distribution due to disturbances such as forest fires, which are predicted from the forcing climatic conditions and the simulated vegetation (the "fuel"). As such, the model's estimates of vegetation attributes (such as standing wood volume and annual wood productivity [m^3 ha^{-1} yr^{-1}] for softwoods and hardwoods; see below) do take some account of the effects of disturbance. Can-IBIS does not explicitly account for the effects of fire-suppression practices, but the simulated average annual area burned was calibrated against the results obtained from high-resolution fire modeling with BURN-P3 (see section below entitled "Wildfire").

Disturbance effects are represented in Can-IBIS only as changes in the areal proportions of young and old stands within each 10-km grid cell; there is no explicit representation of individual stands or sites. On the basis of individual productivity in response to the imposed site conditions, each PFT achieves a certain fraction of total ground cover. Simulated vegetation cover (generally forest or grassland or a mixture) is then classified according to how much of the available space is occupied by each PFT. In addition, each PFT is a generic grouping of plant species that tend to function in similar ways when exposed to similar environmental conditions, even though they may occur in geographically distinct locations. For this reason, there is no attempt within the model to capture genetic differences in ecophysiological responses among species, let alone among individual genotypes within a single species. Instead, each PFT, represented by a unique set of parameters, is assumed to be able to occupy its full geographic range. Competition among PFTs for resources (specifically, water and light) is influenced by differential responses to temperature and soil water content. Hence, as these simulated environmental conditions change within each grid cell, the relative proportions of component PFTs shift, so that what might be classified as boreal mixedwood in one simulated year could become a boreal evergreen conifer forest a few simulated years later. If the environmental conditions change sufficiently, some PFTs may no longer be able to survive and compete, so they will gradually stop growing and will disappear.

When particular PFTs are no longer able to survive, conditions will then generally favor other, more suitable PFTs. The model assumes that these new PFTs will arrive, so long as conditions remain suitable; however, it does not impose any constraints on how rapidly vegetation can produce seed and propagate across the landscape.

The results from dynamic vegetation models such as Can-IBIS should be viewed and interpreted with caution. All models are simplifications of complex systems. Moreover, the further into the future that a model's projections run, the more uncertain its inputs become. For example, the vegetation models used for the Vanderhoof study relied on climate scenarios, which were themselves based on a series of uncertain inputs (e.g., future GHG concentrations). There is also uncertainty in how present-day GCMs represent the responses of the atmosphere when it is subjected to changes in composition. Added to these is the huge uncertainty in the models used to interpret the effects of a changing climate on ecosystems (i.e., uncertainty about model structure and uncertainty about model parameters). Hence, the results presented in this report must be considered only as a guide, albeit one that is based on the best available knowledge. In essence, they are a sensitivity analysis of the possible range of vegetation responses to plausible scenarios of future climate change. These responses should be considered in "relative" terms, both relative to present-day reality and relative to one other.

Vegetation Modeling with Can-IBIS

The Can-IBIS model produces vast amounts of diagnostic output, mostly presented as time-series maps showing changes in each variable at monthly or yearly intervals. Variables discussed in this study are vegetation type (based on the classification of simulated values of leaf area index [leaf area per square meter of ground area] of different PFTs), mean annual increment (MAI, m^3 ha^{-1} yr^{-1}, estimated from simulated annual new growth in woody biomass, aggregated into conifer and broadleaf categories), and standing wood volume (m^3 ha^{-1}, estimated from the simulated woody biomass for all tree PFTs, also aggregated into conifer and broadleaf categories), estimated for each 10 km × 10 km grid cell.

At the Canadian Forest Service Northern Forestry Centre in Edmonton, Can-IBIS runs of several hundred years are performed routinely with a cluster of 30–40 Unix computers (depending on hardware availability). In addition to simulations for the Vanderhoof study area and comparable areas surrounding other rural communities (specifically La Ronge, Saskatchewan, and Victoria Beach, Manitoba), simulations have been performed for Canada and for North America as a whole. In addition, numerous tests of the model have been carried out at individual sites where experimental data have been collected and can be compared directly with the model's output as driven by observed meteorological and soils data. After extensive testing and calibration of the model, a series of Can-IBIS simulations were carried out for the Vanderhoof study area. The initial simulation consisted of a "spin-up" phase, in which the 20th century climate data were detrended (i.e., any systematic changes in temperature or precipitation were removed) and replayed for 200 years. During this phase, the model's internal carbon pools (soils and woody vegetation) were allowed to stabilize. The ending conditions were then used to initialize a 100-year run for the 20th century, during which the observed climatological data were used to simulate the vegetation, allowing an assessment of the model's performance in recreating "present-day" conditions (i.e., for about the year 2000). These results were in turn used to initialize a set of six additional runs for the 21st century, one for each of the GCM and SRES scenario combinations described in the previous section.

Models such as Can-IBIS are being continually improved and refined as new information emerges from observations and experiments and as errors are discovered and corrected (in the progam code and in the parameters used to define how the model behaves). These improvements will affect future model outputs. Therefore, the simulation results reported here should be considered first approximations and subject to revision.

Results of Can-IBIS Simulations

As noted previously, the model has been extensively tested, but its ability to simulate present-day vegetation distribution is far from perfect. It does effectively capture the broad distribution of major natural vegetation zones found across North America today and makes reasonable estimates of key indicators, such as leaf area index, standing biomass, soil carbon content, and primary productivity. In the work reported here, the consistency achieved for the Vanderhoof region was superior to the general standard achieved for the entire continent. To some extent this was because tuning and calibrating the model for a smaller region (simulated at higher spatial resolution) can be easier than developing a universal set of parameters for applications at the much larger continental (or even global) scale. Most of the parameters used in the Vanderhoof project were the same as those used for continental and Canadian national-scale simulations, with only a few adjustments to reflect conditions specific to the Vanderhoof study region. In general, the results (some of which are shown in Figures 22 to 26) are considered reasonable, but they require careful interpretation.

Figure 22 shows the dominant vegetation types (or PFTs) as simulated by Can-IBIS for the Vanderhoof study region for the "present day" (year 2000) and for 2100 under three climate scenarios: CGCM2–A2 (warm and dry), HadCM3–B2 (cool and dry), and CSIRO Mk2–A2 (hot and wet). The present-day map was created after Can-IBIS had simulated 300 years of forest development, and as such, the three scenario maps add 100 years to the simulation period.

Successful prediction of present-day ecosystem conditions is an important criterion for the credibility of future projections. In this study, the simulation of present-day vegetation distribution was reasonably accurate. In reality, the current landscape is dominated by a mixture of boreal or high-elevation conifer species, including lodgepole pine, black spruce (*Picea mariana* (Mill.) BSP), white spruce (*Picea glauca* (Moench) Voss), and Engelmann spruce, interspersed, particularly at lower elevations, with deciduous species, including aspen, other poplars, birches, and willows (*Salix* spp.). When the simulation was performed for 10 km × 10 km grid cells, the model predicted a current landscape

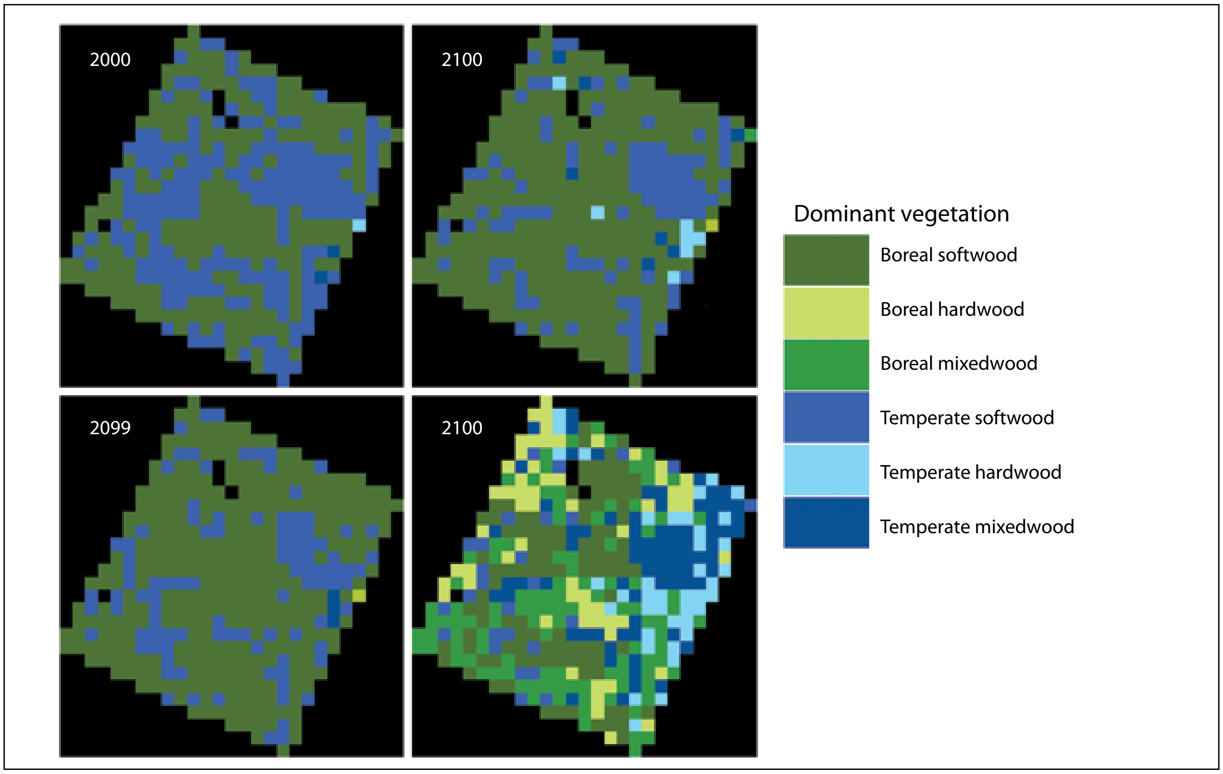


Figure 22. Changes in dominant vegetation as simulated by the Canadian Integrated Biosphere Simulator for the Vanderhoof study region. Top left: present-day vegetation simulated for the year 2000 using historical climate data; top right: for 2100, using climate scenario data from Canadian Second-Generation Coupled Global Climate Model, forced by A2 emissions scenario; bottom left: for 2100 using climate scenario data from Hadley Centre Third-Generation Coupled Model, forced by B2 emissions scenario; bottom right: for 2100 using climate scenario data from Commonwealth Scientific and Industrial Research Organization Mark 2 model, forced by A2 emissions scenario. Each scenario has been identified according to the characteristic changes in temperature and precipitation as projected for this particular study region. A2 = scenario with a regionalized global economy in which the rate of increase in greenhouse gas emissions is comparable to the rate of increase in the 1990s. B2 = scenario with a regionalized global economy in which societies are more socially and environmentally conscious than in scenario A2, with slower population growth, lower energy intensity, and less reliance on fossil fuels, leading to a much lower rate of growth in greenhouse gas emissions.

dominated by boreal or temperate conifers, with a relatively small deciduous component. This result is consistent with the Can-IBIS rules for determining vegetation classification, which overlook small proportions of competing species. Deciduous broad-leaved boreal and temperate PFTs were present in the simulated vegetation but did not feature significantly in the final classification. The split between "temperate" and "boreal" conifer types is more difficult to explain. In essence, the model was configured to reproduce temperate forest in truly temperate regions (such as the Pacific coast, extending from northern California to the Gulf of Alaska) and the eastern seaboard, from northern Florida to the Maritime and Laurentian regions of Canada. Similarly, there was an attempt to have Can-IBIS simulate boreal forest (conifer, deciduous, and mixed) in the central regions of Canada and Alaska. The model's apparent confusion probably relates to the fact that the Vanderhoof region falls climatically somewhere between a true temperate and a true boreal environment. It is somewhat milder and damper than the boreal region east of the Rocky Mountains, with most rain falling in winter rather than summer, but it is also considerably drier and cooler in winter than the coastal temperate regions to the west. Within the model, two important PFTs in the Vanderhoof region were "dry boreal needleleaf evergreen" and "cool temperate needleleaf evergreen." Either of these might be an appropriate classification for lodgepole pine in British Columbia, which perhaps demonstrates a shortcoming of the PFT approach. Can-IBIS has thus simulated a competition between these two coniferous PFTs, with some grid cells falling to the temperate side and some to the boreal side, depending on the combination of soil type, climate data, and elevation. Hence, this result is about as good as can be expected without simulating the landscape at higher resolution (which would require a greater investment in database construction and further testing of the model).

The projections of future forest composition using the CGCM2–A2 and HadCM3–B2 scenarios in Figure 22 were similar, with only relatively minor changes in composition occurring between 2000 and 2100. The warmer and dryer conditions result in some increase in the boreal component and also favor more drought-adapted species such as lodgepole pine. The CSIRO Mk2–A2 scenario (which projects significant increases in annual precipitation in addition to the greatest warming) results in a major change in forest composition, with hardwood species becoming dominant throughout most of the region.

Figure 23 (softwood) and Figure 24 (hardwood) show the simulated results for MAI as projected by Can-IBIS for the Vanderhoof study region for the "present day" (year 2000) and for 2100 under the same three climate scenarios used for Figure 22. These results are consistent with the general results shown in Figure 22. For present-day conditions, simulated MAI varies over the range 0 to 8 m^3 ha^{-1} yr^{-1} but is close to zero for hardwoods. These values for MAI are reasonable, given that they were averaged over a 10 km × 10 km grid cell (i.e., the low values for the hardwood components reflect their small contribution to total vegetation cover in a grid cell rather than implying low productivity at the stand level). The two drier scenarios (CGCM2–A2 and HadCM3–B2) projected significant increases in productivity with climate change, probably because of a combination of increased CO_2 concentration ("CO_2 fertilization") and extended growing seasons (i.e., higher mean summer temperatures) in a region where annual precipitation is generally adequate. The greatest increase in productivity shown in Figures 23 and 24 occurred with the HadCM3–B2 scenario (which had the smallest temperature increase but also a smaller increase in CO_2 concentration). It should be noted, though, that the HadCM3–A2 scenario yielded even greater increases in productivity, because the relatively small projected increases in temperature were combined with larger increases in CO_2 concentration.[4] Overall, these results suggest that greater warming (i.e., as projected by the CGCM2 and CSIRO Mk2 models) will eventually have negative impacts on productivity, unless there is a shift in forest composition toward new species that are better adapted to the warmer conditions (see Appendix 4). The warmer and wetter CSIRO Mk2–A2 scenario showed significant decreases in conifer productivity, which were compensated by major increases in hardwood production, although overall productivity declined in 2100 relative to current MAI. This result is directly related to the projected decline in conifer dominance and the shift in composition toward hardwoods. Interestingly, the CGCM2–A2 scenario also produced an increase in hardwood productivity, although it was clearly much less significant than that generated by the CSIRO Mk2–A2 scenario.

The projections of standing timber volume in 2100 (Figures 25 and 26) are perhaps the most contentious results obtained in this portion of the study, because Can-IBIS predicted present-day standing wood volumes considerably higher than have generally been observed—although it should be recognized that the modeled estimates represent total volume (derived from simulated wood biomass) rather than merchantable volume. This biased result is likely the result of incorrect model parameters or incorrect model specifications, and work is under way to resolve it. One possible cause of the problem is an internal assumption about the longevity of tree biomass, which is likely higher than it should be. Reducing this value for a tree PFT will shorten the effective mean lifetime and will also reduce the respiratory "tax" imposed on woody biomass, which affects productivity (i.e., shorter life span will mean lower standing volume [averaged over a grid cell] combined with higher mean annual increment). It remains to be seen whether making such a change will keep MAI within a reasonable range while greatly reducing the overestimate of standing volume.

[4]This is illustrated later in the report in Figure 33. Figure 33 also shows that the productivity multiplier determined with the CGCM2–A2 climate and emissions scenario was slightly higher than that determined with the HadCM3–B2 scenario.

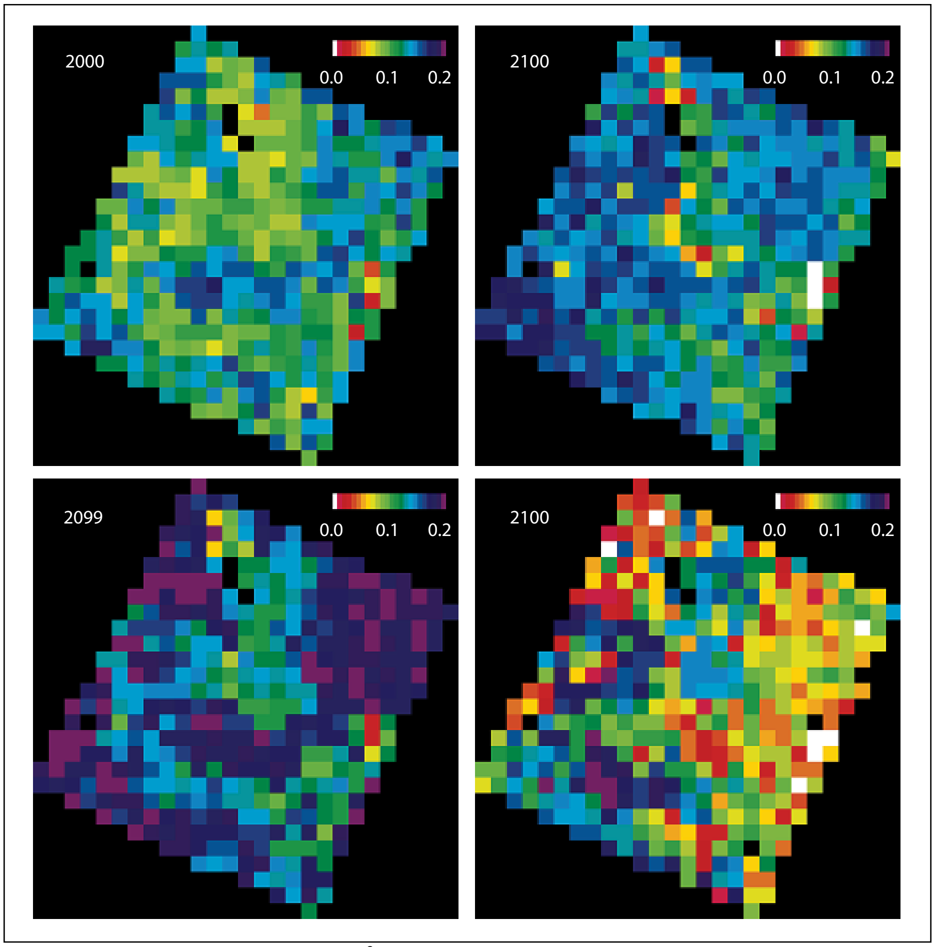


Figure 23. Annual softwood production (m^3/ha) simulated by the Canadian Integrated Biosphere Simulator for the Vanderhoof study region. Top left: for the year 2000 using historical climate data; top right: for 2100, using climate scenario data from Canadian Second-Generation Coupled Global Climate Model, forced by A2 emissions scenario; bottom left: for 2100 using climate scenario data from Hadley Centre Third-Generation Coupled Model, forced by B2 emissions scenario; bottom right: for 2100 using climate scenario data from Commonwealth Scientific and Industrial Research Organization Mark 2 model, forced by A2 emissions scenario. A2 = scenario with a regionalized global economy in which the rate of increase in greenhouse gas emissions is comparable to the rate of increase in the 1990s. B2 = scenario with a regionalized global economy in which societies are more socially and environmentally conscious than in scenario A2, with slower population growth, lower energy intensity, and less reliance on fossil fuels, leading to a much lower rate of growth in greenhouse gas emissions.

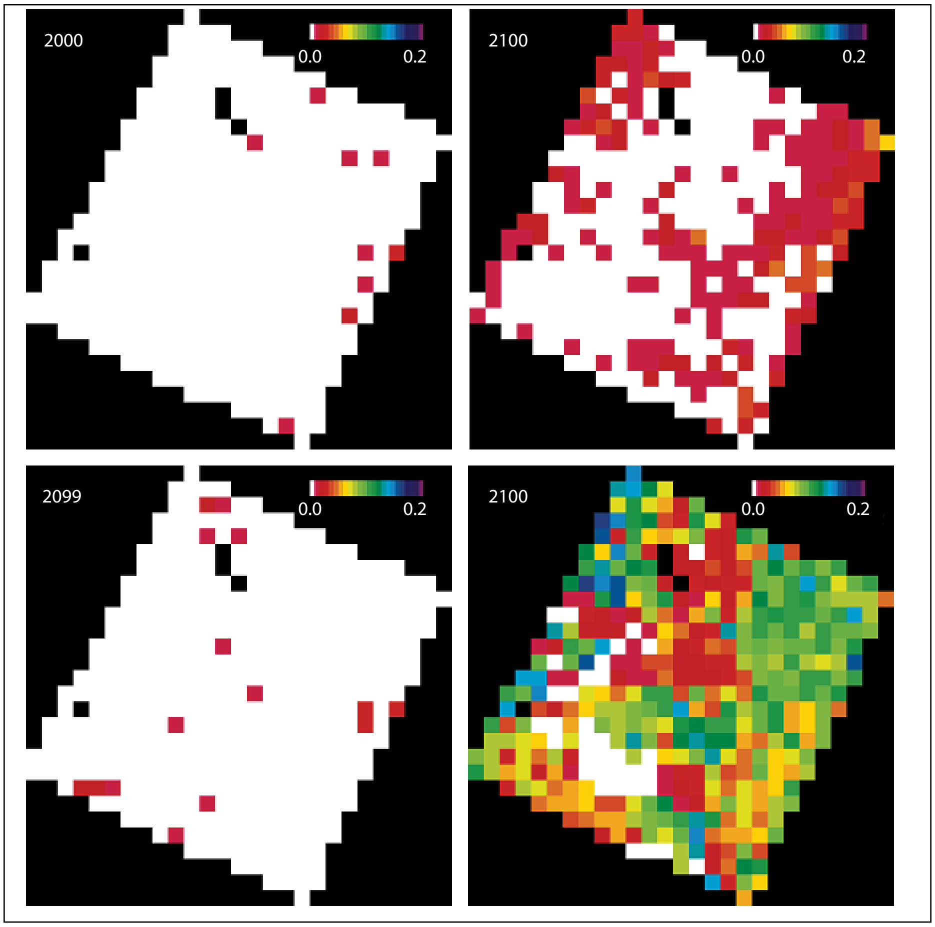


Figure 24. Annual hardwood production (m^3/ha) simulated by the Canadian Integrated Biosphere Simulator for the Vanderhoof study region. Top left: for the year 2000 using historical climate data; top right: for 2100, using climate scenario data from Canadian Second-Generation Coupled Global Climate Model, forced by A2 emissions scenario; bottom left: for 2100 using climate scenario data from Hadley Centre Third-Generation Coupled Model, forced by B2 emissions scenario; bottom right: for 2100 using climate scenario data from Commonwealth Scientific and Industrial Research Organization Mark 2 model, forced by A2 emissions scenario. The low-productivity values shown here reflect the small contribution of hardwood trees to total vegetation cover in a grid cell more than they imply low productivity of individual stands. A2 = scenario with a regionalized global economy in which the rate of increase in greenhouse gas emissions is comparable to the rate of increase in the 1990s. B2 = scenario with a regionalized global economy in which societies are more socially and environmentally conscious than in scenario A2, with slower population growth, lower energy intensity, and less reliance on fossil fuels, leading to a much lower rate of growth in greenhouse gas emissions.

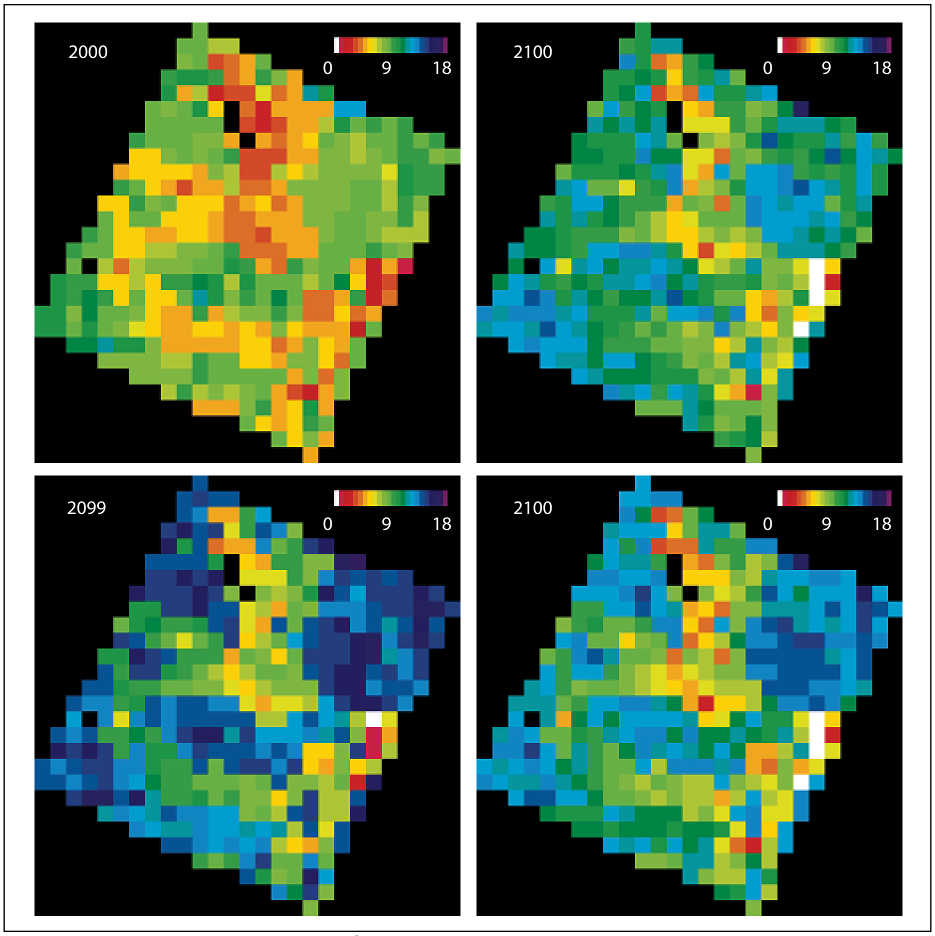


Figure 25. Softwood standing timber (m^3/ha) simulated by the Canadian Integrated Biosphere Simulator for the Vanderhoof study region. Top left: for the year 2000 using historical climate data; top right: for 2100, using climate scenario data from Canadian Second-Generation Coupled Global Climate Model, forced by A2 emissions scenario; bottom left: for 2100 using climate scenario data from Hadley Centre Third-Generation Coupled Model, forced by B2 emissions scenario; bottom right: for 2100 using climate scenario data from Commonwealth Scientific and Industrial Research Organization Mark 2 model, forced by A2 emissions scenario. A2 = scenario with a regionalized global economy in which the rate of increase in greenhouse gas emissions is comparable to the rate of increase in the 1990s. B2 = scenario with a regionalized global economy in which societies are more socially and environmentally conscious than in scenario A2, with slower population growth, lower energy intensity, and less reliance on fossil fuels, leading to a much lower rate of growth in greenhouse gas emissions.

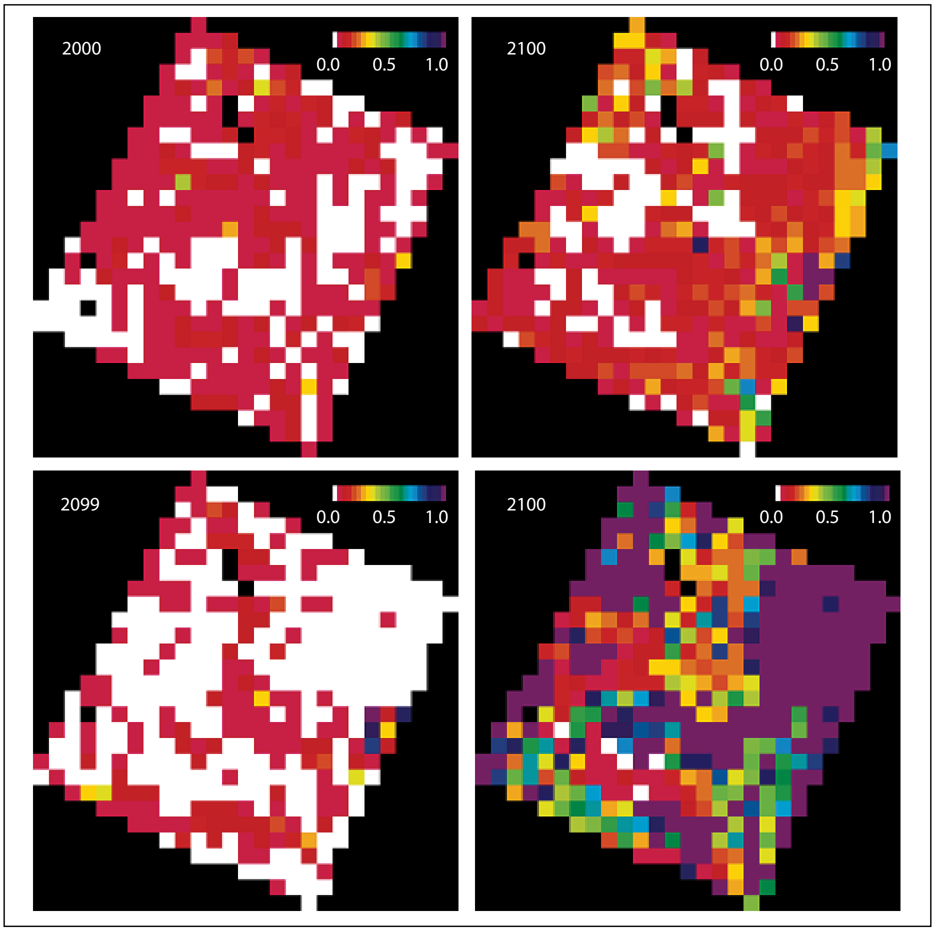


Figure 26. Hardwood standing timber (m^3/ha) simulated by the Canadian Integrated Biosphere Simulator for the Vanderhoof study region. Top left: for the year 2000 using historical climate data; top right: for 2100, using climate scenario data from Canadian Second-Generation Coupled Global Climate Model, forced by A2 emissions scenario; bottom left: for 2100 using climate scenario data from Hadley Centre Third-Generation Coupled Model, forced by B2 emissions scenario; bottom right: for 2100 using climate scenario data from Commonwealth Scientific and Industrial Research Organization Mark 2 model, forced by A2 emissions scenario. A2 = scenario with a regionalized global economy in which the rate of increase in greenhouse gas emissions is comparable to the rate of increase in the 1990s. B2 = scenario with a regionalized global economy in which societies are more socially and environmentally conscious than in scenario A2, with slower population growth, lower energy intensity, and less reliance on fossil fuels, leading to a much lower rate of growth in greenhouse gas emissions.

The different climate scenarios all projected significant increases in wood volume, consistent with the increases in productivity resulting from CO_2 fertilization. Of the three scenarios, the increases were greatest with the cool, dry, low-CO_2 HadCM3–B2 scenario; the CSIRO Mk2–A2 scenario also promoted significant increases in hardwood volume, although not enough to balance the loss of softwood volume relative to HadCM3–B2. Given the tendency of the model to overestimate standing volume, these results should all be treated with caution.

It is questionable whether wetter conditions would necessarily promote an increase in the proportion of deciduous forest, but there is circumstantial evidence to support this outcome. For example, Waring and Franklin (1979) pointed to the dominance of conifer forest in the Pacific Northwest, rather than the hardwood-dominated forests seen in the eastern United States and southeastern Canada. They attributed this difference to the occurrence of dry summers (and mild wet winters) in the Pacific region and wet summers in the east.

Discussion

Caution in interpreting and using modeled predictions of the future is particularly important when simulating the effects of changes in environmental conditions on natural ecosystems that go beyond previously observed limits—exactly what is being asked of models such as Can-IBIS. Although the modeled temperatures and other climatic variables may already occur in similar combinations in other parts of the world, there could be important interactions (e.g., caused by increasing CO_2 concentration) that have never been observed in recorded history. Therefore, it cannot be known with any certainty whether Can-IBIS is simulating these interactions realistically. In their recent meta-analysis of observations obtained in the Free Air CO_2 Enrichment experiments in the United States and Europe, Norby et al. (2005) concluded that elevated CO_2 concentrations will increase forest productivity, at least in immature stands. Other work, notably that by Körner et al. (2005) for mature hardwood forest, indicated no significant increase in stemwood production with increasing CO_2; instead, these authors found that additional photosynthate would be lost in decomposable litter and/or with higher respiration rates. Yet these results cannot be considered definitive either, because warmer, drier conditions are likely to promote faster mineralization of organically bound N that is currently locked up in the cold, wet soils found in many Canadian forests. Can-IBIS projected rather smaller increases in productivity due to increasing CO_2 than those reported by Norby et al. (2005), whereas its representation of temperature and moisture effects on soil N was limited by a lack of detailed soils information. Hence, the responses projected by Can-IBIS are conservative but could still be incorrect.

Overall, then, projections of increases in MAI and total wood volume per hectare (i.e., relative to the values simulated for the present day) may be reasonable responses to the projected changes in climate (probably warmer, possibly wetter) combined with increases in atmospheric CO_2. The results do not, however, take proper account of the likely increased losses due to catastrophic natural disturbances (particularly insects, but also fires). The recent impacts of MPB in the interior of British Columbia demonstrate the enormous potential for "unexpected surprises" to alter the trajectory of stand- and landscape-level processes. Therefore, the possibility of unexpected events like the MPB outbreak must be kept in mind, and complete reliance on modeled projections avoided.

In modeling the forest impacts of climate change in the Vanderhoof study area, it was not possible to account for the effects of MPB or other insect pests, although this will be attempted in the near future. Conversely, Can-IBIS was able to simulate the effects of fire, and the sensitivity of those effects to changes in climate and vegetation composition, but apart from a slight increase in the average area burned, the effects appeared relatively small (discussed in more detail in the following section, "Wildfire"). This may be a realistic output or it may be an underestimate related to model limitations (for example, the analysis in the following section suggests that under the CGCM2–B2 scenario, fire susceptibility between 2041 and 2060 would increase significantly). Of particular relevance here is the fact that it was not possible to consider the substantial interaction between beetle-related tree mortality and susceptibility to fire. It may take some years to fully understand these effects and hence to successfully capture them in a large-scale dynamic vegetation model. For example, the MPB outbreak may persist, with generally warmer winters resulting in frequent episodes of pine mortality over small areas. Over time, this effect, combined with human management (e.g., salvage logging, sanitation felling) would cause fragmentation of the landscape to an extent not seen when fires were the only major disturbance agent. This fragmentation might lead to reductions in the areas affected by both insects and fire. At the same time, the continued attack of lodgepole pine by MPB would presumably cause it to lose dominance in the landscape, leading to the possibility that other species, notably hardwoods such as aspen, would take over, which would greatly change the appearance and productivity of the forest. Of course, such changes in forest composition would be followed by the appearance of new pest species and changes in disturbance regimes.

To summarize, it seems plausible that the general trend of milder winters and longer growing seasons, coupled with increasing CO_2 concentration and the possibility of an increase in average annual rainfall, will favor an increase in forest growth. The model projects a tendency toward an increasing proportion of hardwoods, but this becomes significant in only one out of three scenarios (produced by the CSIRO Mk2 model) (see Figure 22). Consistent with an increase in hardwood content is an increase in hardwood productivity, but again, this would be significant only with the CSIRO Mk2 model. Even with that model, hardwood content would account for only 10%–20% of total standing volume (Figures 25 and 26), which is probably comparable to what exists today, averaged over the landscape.

At the same time, it is very likely that any gains in productivity due to climate change and higher CO_2 concentration will be offset by increased losses due to fire, insects, or drought. A common belief is that climate will exhibit greater statistical variability in the future than it did in the past, leading to more intense storms and more intense droughts (periods of lower-than-average rainfall coupled with warmer-than-average temperatures). Greater losses can therefore be anticipated, due not only to fires and insects but possibly also to droughts and storms.

Wildfire

Objective

The potential for a forest fire to ignite and spread across an area is heavily influenced by the day-to-day weather conditions over the course of the fire season, which determine the moisture content of forest fuels and the fire behavior potential at a given point in time. The objective of this part of the study was to assess the impacts of climate change on fire weather, and subsequent fire susceptibility, in the Vanderhoof study area.

Methods

The Canadian Fire Weather Index (FWI) System (Van Wagner 1987) provides relative ratings of how changes in temperature, relative humidity, wind, and precipitation affect fuel moisture and fire behavior potential. FWI System components are calculated daily for individual weather stations throughout the fire season. Because projections of daily climate data required for calculation of future FWI System components were not readily available, daily values were approximated from the GCM projections of monthly values presented earlier, according to a method described by Flannigan and Van Wagner (1991). This approach involves calculating mean monthly variations in climate model outputs relative to baseline conditions and then adjusting daily historical records to account for the differences. Actual fire weather and FWI records for the period 1984–2004 from weather stations in the study area, obtained from the British Columbia Ministry of Forests and Range (BCMOFR), were used to represent baseline daily fire weather conditions. These records were adjusted using climate model outputs to produce projected daily fire weather conditions for the period 2041–2060.

To investigate changes in fire susceptibility under these projected future fire weather conditions, landscape simulation modeling was used. Fire susceptibility is influenced by a number of factors in addition to weather, including vegetation (fuel), topographic conditions, and ignition sources. At any location on the landscape, these factors can combine to either promote or limit the potential for a fire to ignite and spread, and methods for assessing the collective contribution of these factors have been developed. A common approach is to rate locations on the basis of the characteristics that are present, such as fuel type (e.g., Hawkes and Beck 1997). Landscape simulation modeling has emerged as a valuable tool for capturing interactions among the factors that influence fire susceptibility. Because such models simulate the spread of forest fires across the landscape, they incorporate the influence of adjacent areas on fire susceptibility at the given location.

For the purposes of this study, BURN-P3 (Parisien et al. 2005) was used to model fire susceptibility in the Vanderhoof area. The core mechanics of this model involve repeated simulations of a single fire year (i.e., fire season). During each simulation, fire ignitions are initiated in the study area, and a fire growth model (Prometheus) is used to grow each fire, according to the Canadian Forest Fire Behavior Prediction (FBP) System (Forestry Canada Fire Danger Group 1992). The FBP System combines fire weather information described in the FWI System components with fuel-type data to predict the spread of the fire, repeating the process for 10 000 iterations or more. As the iterations progress, the model keeps track of how many times each location in the landscape burns.

Fire susceptibility, which is assessed for each 100 m × 100 m pixel in the landscape grid, is evaluated as the actual number of times a fire burned the pixel in relation to the total number of opportunities for the pixel to burn (i.e., the number of model runs or iterations). The resulting values are smoothed at a 2-km radius and assigned a qualitative index that rates fire susceptibility rating: low, moderate, high, or extreme. This approach produces a high correspondence between replicated fire-susceptibility maps (Parisien et al. 2005).

Fire processes in the model are controlled by inputs derived from an assessment of historical fire and weather activity (see Appendix 2 for a detailed description of model inputs). The inputs incorporate known patterns of fire activity across the study area, seasonal characteristics of the area, patterns of escaped fires, fire-size distributions, topography, fuel conditions, and weather conditions. The BURN-P3 model does not attempt to account for other ecosystem processes or changes in landscape characteristics such as vegetation succession because these conditions are assumed to remain stable throughout the relatively short duration of a single fire season. Hence, vegetation conditions for the fire season are input into the model and remain static throughout the simulations.

The fire growth model, which is embedded within BURN-P3, requires relatively fine-scale vegetation data, which must be represented as FBP System fuel types. The most recent FBP fuel-type classification of the study area was obtained from the BCMOFR. The map was completed in 1999, and therefore represented conditions before the MPB outbreak. To create a map of current FBP fuel types, data were obtained on the extent of MPB-affected areas (from S. Taylor, fire researcher, Pacific Forestry Centre, Victoria, British Columbia), and experts were consulted about the appropriate fuel-type classification for these areas (S. Harvey, senior project officer, Prince George Fire Centre, BCMOFR, Prince George, British Columbia; D. Marek, forest protection technician, Northwest Fires Centre, BCMOFR, Smithers, British Columbia; N. Lavoie, leader, Fire Sciences, BCMOFR, Fire Management Section, Victoria, British Columbia; S. Taylor, fire researcher, Pacific Forestry Centre, Victoria, British Columbia; personal communications via face-to-face meetings held in June 2005). Because there was no fine-scale succession model capable of producing future FBP fuel conditions under the climate change scenarios, fuel conditions for the period 2041–2060 period were based largely on the optimistic assumption that areas currently affected by MPB would have low flammability during the period of interest (see Appendix 2 for further details).

The vegetation and weather data were combined to produce 4 modeling scenarios for the BURN-P3 model: the baseline scenario, in which fire susceptibility was modeled with fuel inputs representative of conditions before the MPB outbreak and weather inputs representative of baseline conditions (1985–2004); the current conditions scenario, in which fire susceptibility was modeled with fuel inputs representative of conditions in 2004 (when fuels affected by the MPB were in a state of high flammability), after the MPB had progressed across the study area, and weather inputs were representative of baseline conditions (1985–2004); the low-flammability without climate change scenario, in which fire susceptibility was modeled with fuel and weather inputs predicted to occur in the period 2041–2060, assuming that fuels currently affected by MPB will be in a relatively low-flammability state and weather conditions will be unchanged from baseline conditions (1985–2004); and the low-flammability with climate change scenario, in which fire susceptibility was modeled with fuel and weather inputs predicted to occur in 2041–2060, assuming that fuels currently affected by MPB will be in a relatively low-flammability state and weather conditions will be altered by climate change conditions as output by the CGCM2 combined with the B2 emissions scenario (see Appendix 2 for details). The results of the four modeling scenarios were compared, and implications for fire and land management are discussed here.

Results and Discussion

Results for the four BURN-P3 simulations are shown in Figure 27. According to the baseline scenario, the majority of the area (79%) was characterized by relatively low fire susceptibility before the MPB outbreak (Figure 28). The other 3 scenarios were assessed relative to this baseline.

The current conditions scenario represented conditions in 2004, after study area fuels had been affected by the MPB outbreak. This scenario had a significant increase in fire susceptibility relative to baseline conditions (Figure 29), specifically a 76% increase in areas with moderate fire susceptibility, a 169% increase in areas with high fire susceptibility, and a 184% increase in areas with extreme fire susceptibility (although areas with extreme susceptibility occupied less than 0.05% of the study area). An analysis of the fuel types associated with each susceptibility class (Figure 30) revealed the impact of altering fuels to reflect red-stage MPB areas. Areas classified as having moderate susceptibility or high or extreme susceptibility contained a significant component (40%) of the C-2 fuel type (nominally the Boreal Spruce fuel type), the fuel type chosen to approximate red-stage MPB areas.

The scenario of low flammability with no climate change was based on the assumptions that any areas affected by the MPB under the current conditions scenario would be in a state of relatively low flammability between 2041 and 2060 and that weather during this period would be unchanged from baseline conditions (1985–2004). Results from this scenario suggest that low-flammability fuels combined with constant weather would result in a considerable reduction in fire susceptibility across the study area (Figures 27, 28, and 29), specifically a 19% increase in low-susceptibility areas and a 70%, 96%, and 100% decrease in areas with moderate, high, and extreme susceptibility (Figure 29).

The scenario of low flammability with climate change was also based on the assumption that any areas affected by the MPB under the current conditions scenario would be in a state of relatively low flammability between 2041 and 2060; however, it was further assumed that the weather during this period would be altered by predicted climate change, based on the CGCM2–B2 scenario. Relative to baseline conditions, the low flammability with climate change scenario produced changes in fire susceptibility similar to those generated by the current conditions scenario (Figures 27, 28 and 29). This result suggests that even under a very optimistic assumption about the low flammability of future fuels, predicted changes in future weather could produce increases in fire susceptibility equivalent to recent changes associated with MPB impacts (as illustrated by the comparison between the baseline and current conditions scenarios). Under predicted fire weather conditions, the BURN-P3 results suggest that there could be a 96%, 60%, and 59% increase in areas with moderate, high, and extreme fire susceptibility.

Conclusions

The fire susceptibility maps produced for each of these scenarios (Figure 27) indicate spatial variation in the potential for a forest fire to ignite and spread across an area. The modeling results reflect variations in influential factors such as vegetation (fuel type), topographic conditions, and weather, which combine to either promote or limit the potential for a fire to ignite and spread. Simulation modeling with BURN-P3 provides a useful method for integrating the complex interactions among these factors, while also accounting for the spatial context that will affect the nature of these interactions.

The results indicate that the study area is currently experiencing an intensification of fire susceptibility through a change in fuels related to the MPB outbreak: 17.3% of the study area that was originally classified as having low fire susceptibility has been reclassified as having either moderate (15.0%) or high (2.3%) fire susceptibility. The modeling results for the baseline and current condition scenarios are based on the best available fuel, weather, and fire data, but the BURN-P3 model requires several important assumptions about these data. Notably, fire processes are assumed to be unchanged from conditions observed over the baseline period 1970–2002, used to define BURN-P3 inputs such as fire sizes and escaped fire numbers, and weather conditions are assumed to be unchanged from conditions observed over the period 1985–2002, used to define baseline fire weather pools. Assumptions were also made about the fuel types used to simulate the growth of fires in the red- and gray-stage areas of MPB outbreak.

Because BURN-P3 was not specifically designed for modeling future conditions, there are numerous limitations associated with the two scenarios related to future conditions. First, there is considerable uncertainty about what will happen to the vegetation in vast areas of the study area once the MPB outbreak subsides. The results described here are based on simplistic assumptions about future fuels and associated fire behavior and should be considered highly conservative with regard to the potential impacts of fuel on future fire susceptibility. Second, the climate change scenario assumes that some underlying fire processes will remain largely unchanged from those observed during the baseline period (1970–2002). For example, no attempt was made to predict how future fire weather and fuel changes might affect BURN-P3 inputs such as the fire size distribution used to calibrate the model. There was an attempt to account for changes in the number of escaped fires per year, but these estimates were based on a somewhat weak statistical model (see Appendix 2).

Despite these assumptions, the modeling results do offer some insight into the changes in fire susceptibility that may be expected, given predicted changes in fire weather. Predicted increases in the proportion of days in the fire season with critical fire weather (Initial Spread Index ≥ 20 or Fire Weather Index ≥ 46)[5] ranged from 31% to 118% for the six climate change models that were investigated. BURN-P3 results based on future fire weather, as predicted by the CGCM2 forced by the B2 emissions scenario, and an optimistic assumption that areas affected by the current MPB outbreak would remain in a low-flammability state for 35–55 years, indicate a dramatic intensification of fire susceptibility across the study area. This can be considered a conservative estimate of the impacts of climate change on fire susceptibility. Under an assumption of moderate or high flammability for future fuels, such impacts can be expected to intensify.

[5]For an explanation of these terms, refer to the following link: http://www.nofc.forestry.ca/fire/research/environment/cffdrs/fwi_e.htm.

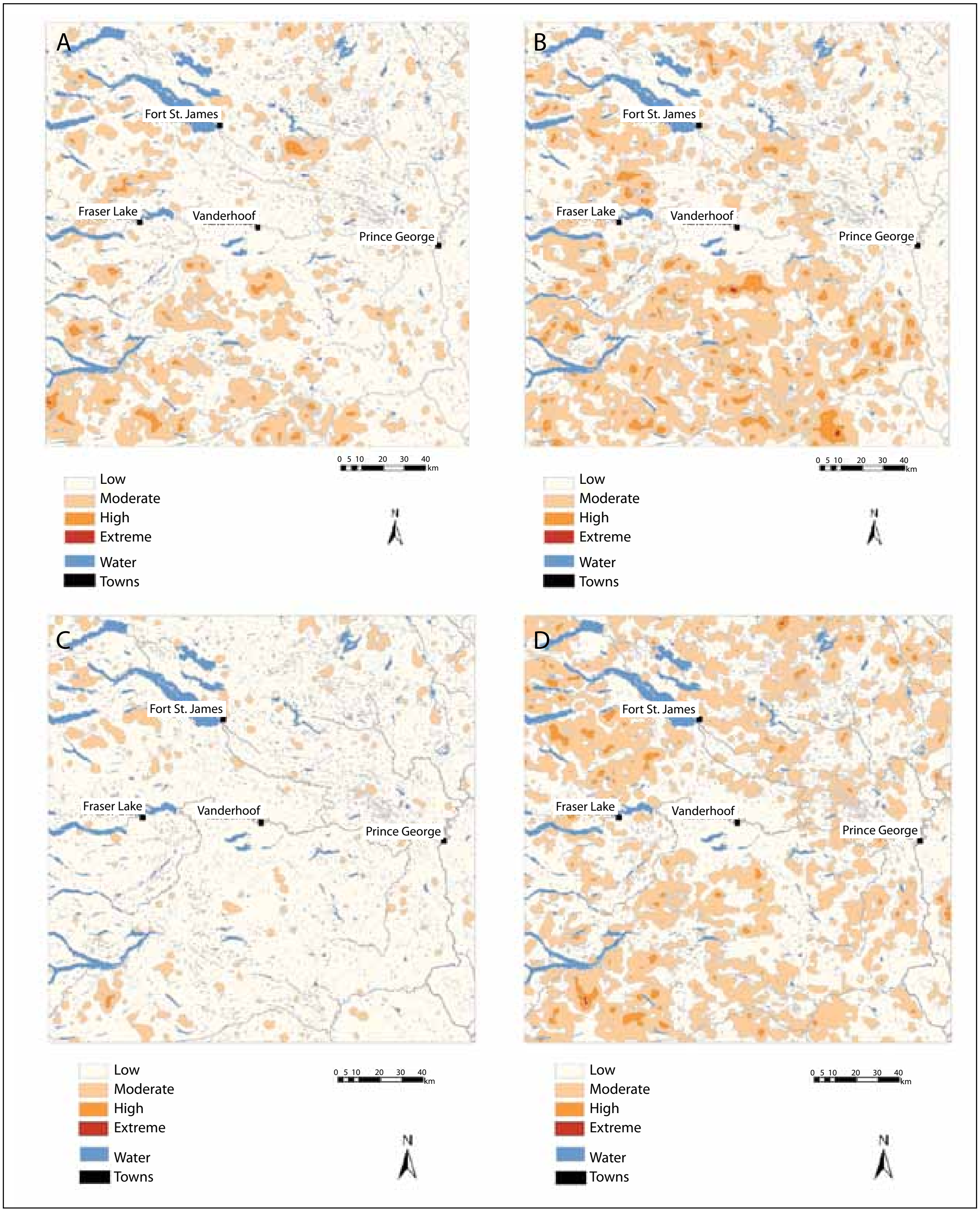


Figure 27. Fire susceptibility classification for the Vanderhoof study area under various past, present, and future conditions. A. Baseline scenario (before mountain pine beetle outbreak). B. Current fuel conditions. C. Future fuels (no climate change). D. Future fuels (with climate change).

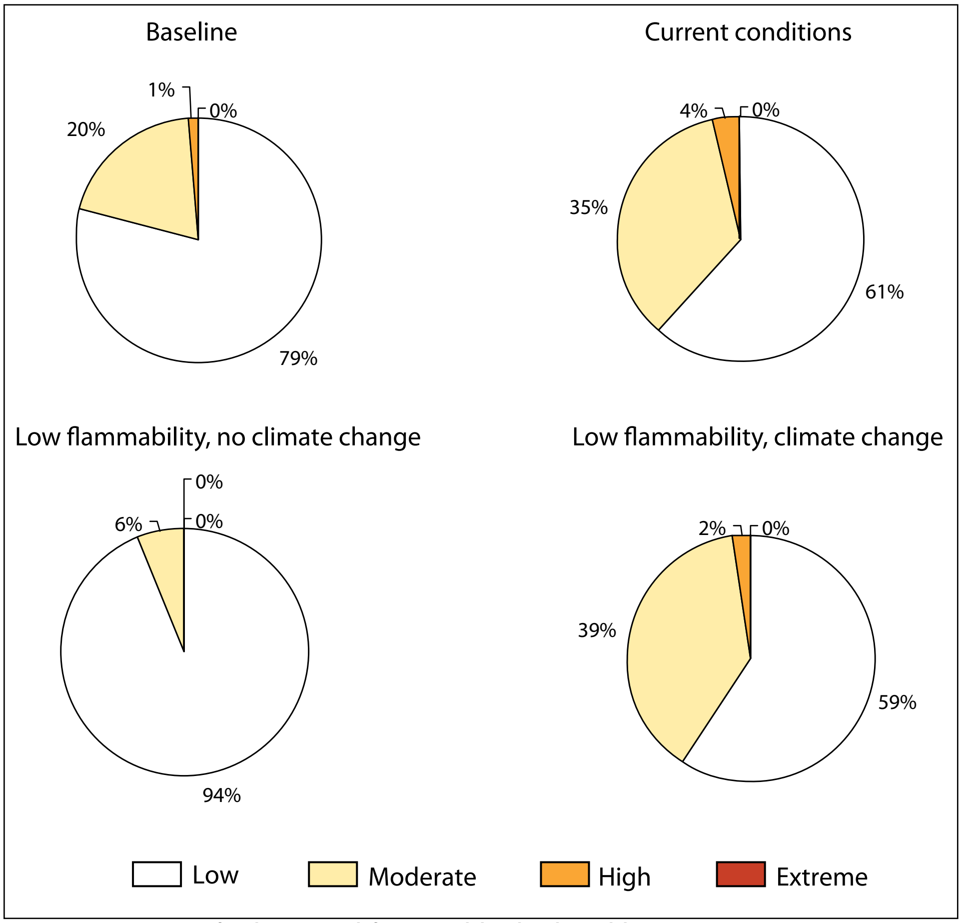


Figure 28. Proportion of study area in each fire susceptibility class, by modeling scenario.

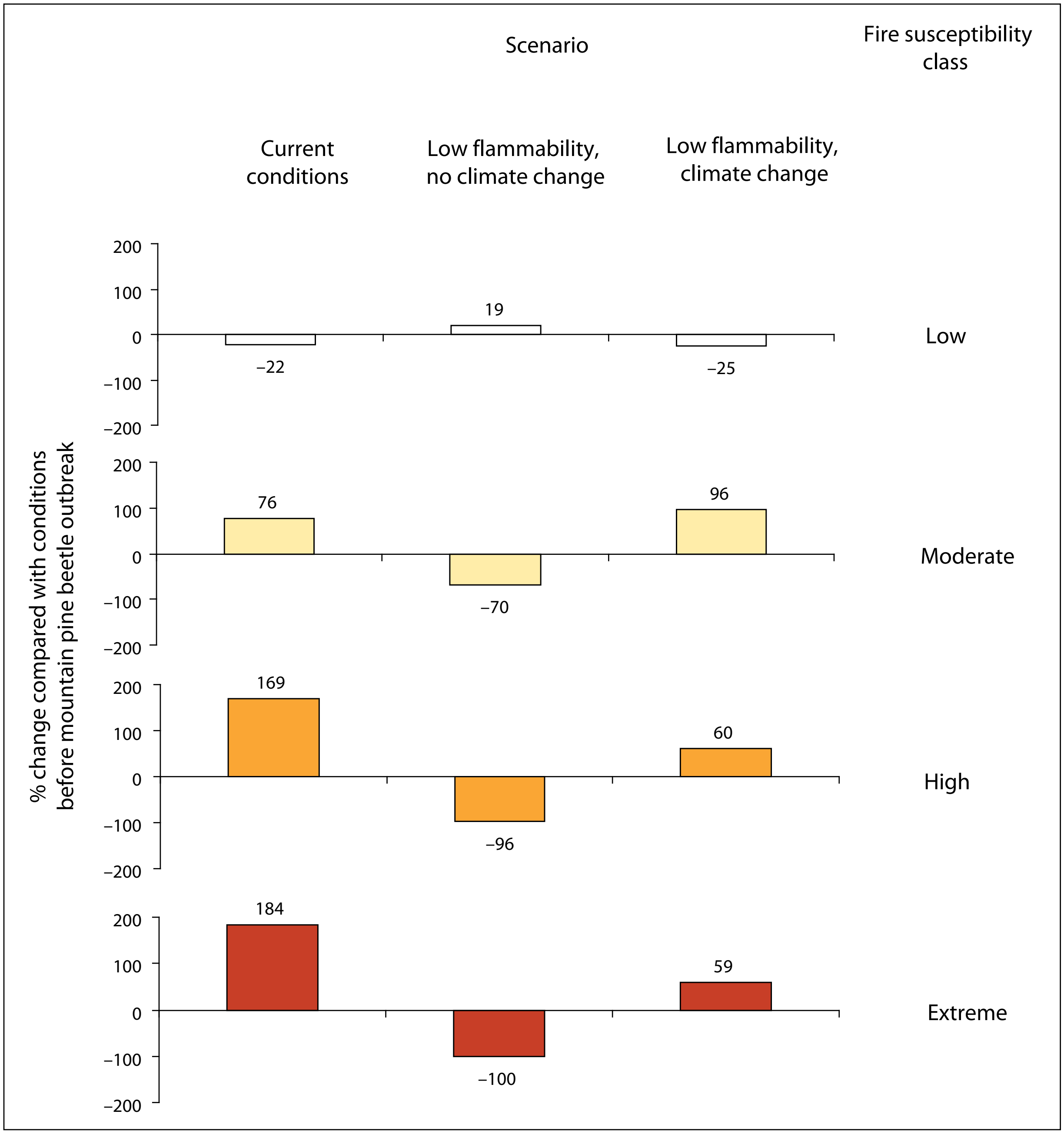


Figure 29. **Percent change in the area characterized by each fire susceptibility class compared with baseline conditions (before mountain pine beetle outbreak), for three scenarios.**

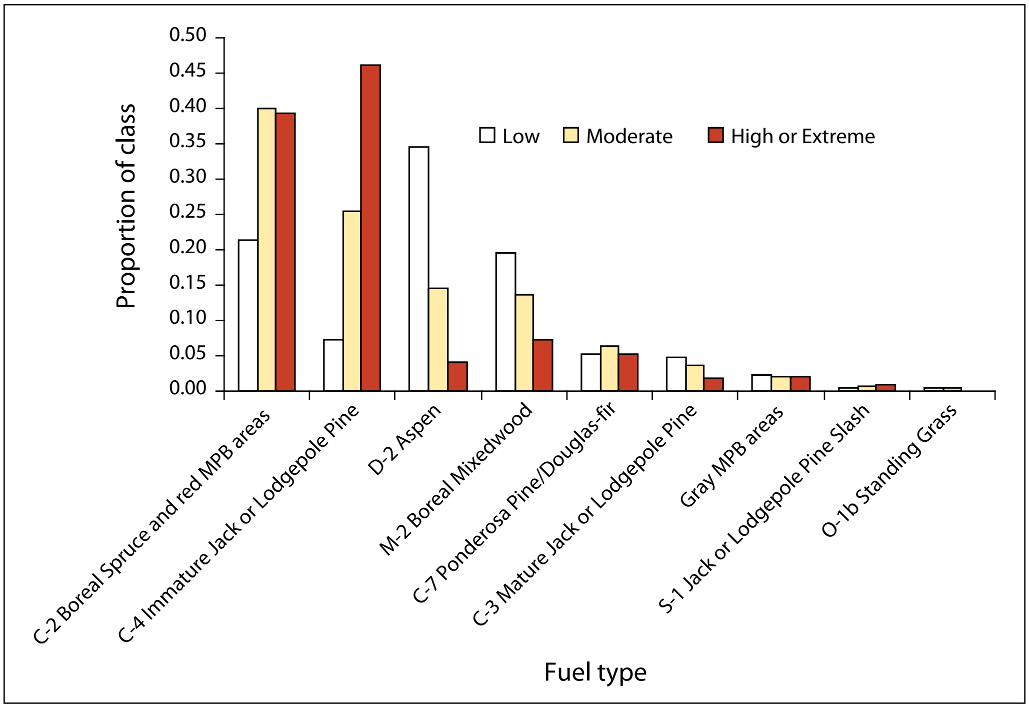


Figure 30. Proportion of each fire susceptibility class that is covered with a given fuel type for the BURN-P3 scenario under current conditions. MPB = mountain pine beetle.

POTENTIAL IMPACTS OF CLIMATE CHANGE ON THE LOCAL ECONOMY

The previous section considered the potential impacts of future climate change on forest ecosystems in the Vanderhoof study area. This section incorporates this information into an analysis of the possible impacts of climate change on the local economy. The study of potential economic impacts of climate change on a resource-based community like Vanderhoof is complex for a number of reasons. First, an analysis of the economic impacts of climate change must be undertaken in the context of broader socioeconomic scenarios. Second, global climate change will affect supply and demand in global forest products markets. Thus, a potentially important impact of climate change for the Canadian forest products industry (and therefore for forest-based communities) is the potential impact on Canadian exports. A third complication pertains to the complexity of modeling required to develop projections of the economic impacts from climate change. This requires an integrated, multidisciplinary approach that translates local biophysical impacts into local economic impacts. It also requires analysis that is based on numerous simplifying assumptions.

This section has four main subsections. The first describes a series of four socioeconomic scenarios for Vanderhoof. The second summarizes previous studies that have investigated the impacts of climate change on global markets for forest products. The third links the biophysical modeling results (presented in the previous section) to an economic model to assess the response of the Vanderhoof economy to various climate scenarios. The final section briefly discusses some other types of impacts that could be experienced in the Vanderhoof study area over the next 50 years.

Socioeconomic Scenarios

Socioeconomic scenarios are an important component of vulnerability assessments (Bell 1997; Yohe et al. 1999; Lorenzoni et al. 2000; Berkhout et al. 2002; Shackley and Deanwood 2003). The analysis of such scenarios is important because the local impacts of climate change will occur at the same time as other, higher-level social and economic trends are affecting communities. Socioeconomic scenarios provide necessary context for assessments of climate change (Feenstra et al. 1998). In fact, it may be difficult to identify the impacts of climate change on a community without taking account of the socioeconomic context (Figure 31). Further background information about the analysis of socioeconomic scenarios is provided in Appendix 3.

The climate scenarios presented in the section entitled "The Climate of the Vanderhoof Study Area" are based on the GHG scenarios presented in the SRES (Nakicenovic and Swart 2000), which are in turn based on a set of defined socioeconomic scenarios. The SRES socioeconomic scenarios consider various alternative paths for economic development, energy use, and technological change for the global economy. This section describes the socioeconomic assumptions underlying the SRES scenarios and attempts to reduce them to a scale relevant to the Vanderhoof context.

Socioeconomic Story Lines: The Global Context

The SRES emissions scenarios were based on four global socioeconomic development story lines (or scenarios), designated A1, A2, B1, and B2. Storylines here refers to the socioeconomic trends and assumptions that underpin the emissions scenarios provided in the SRES. For the purposes of this report, socioeconomic storylines is synonymous with socioeconomic scenarios.

The A1 story line is characterized by strong global economic growth, a midcentury population peak followed by a decline, and rapid introduction of new, more efficient technology (Table 12). The underlying themes for this scenario are economic convergence among regions, capacity-building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income between the developed and developing nations. The A1 scenario results in the highest levels of GHG emissions globally and the greatest change in climate.

The A2 story line is based on a heterogeneous world with self-reliance and preservation of local identities, continuously growing global population, regionally oriented economic development, and slow, fragmented economic growth and technological change (Table 13). The A2 scenario results in the second-highest levels of GHG emissions and CO_2 concentration.

The B1 story line describes a convergent world and the same population trends as the A1 scenario, but with emphasis on global solutions to economic, social, and environmental sustainability. It is characterized by rapid changes toward a service and information economy and a decline in overall materials intensity[6] within the economy (Table 12). This story line results in the lowest levels of GHG emissions and CO_2 concentrations of the four considered.

The B2 story line is similar to A2 with an emphasis on local solutions to economic, social, and environmental sustainability (Table 13). The global population is continuously increasing but at a somewhat slower rate. There are intermediate levels of economic development, and slower and more diverse technological change than in the A1 and B1 story lines. The B2 story line results in the third-highest (second-lowest) levels of GHG emissions and CO_2 concentrations.

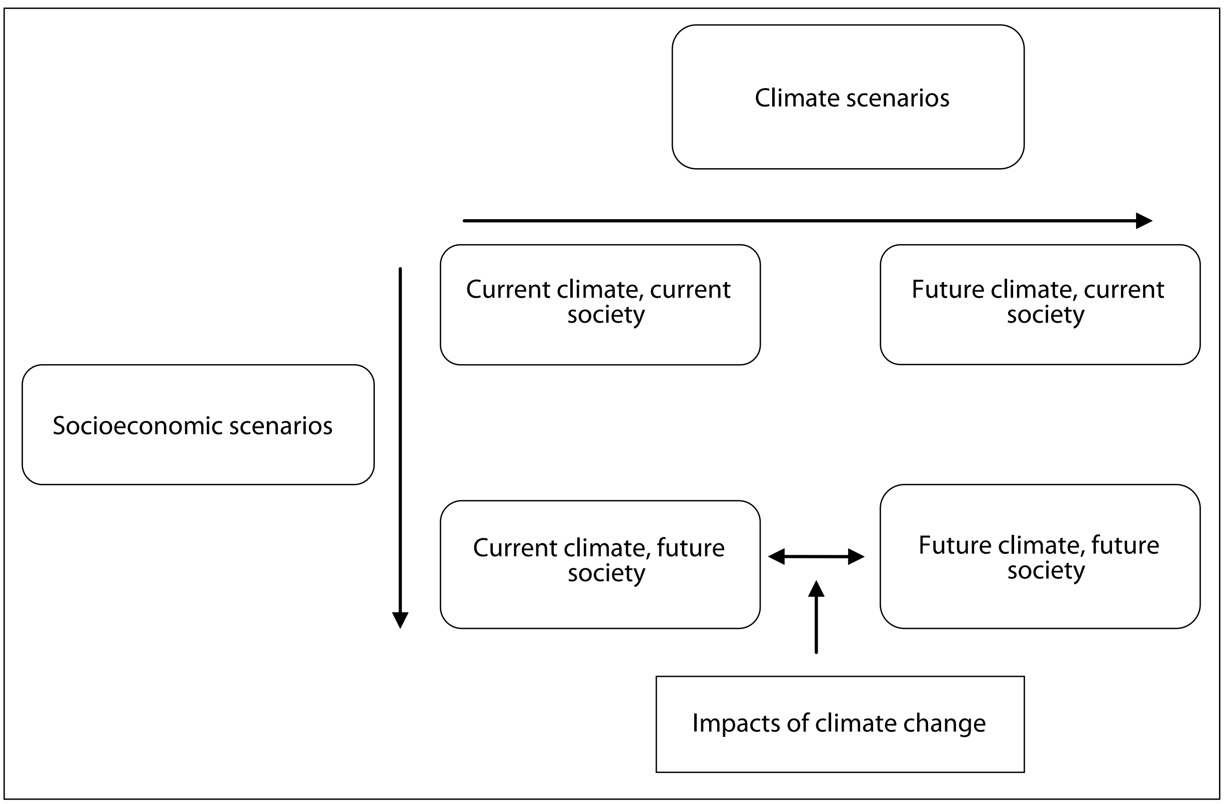


Figure 31. Role of socioeconomic and climate scenarios in assessing impacts of climate change. Source: Feenstra et al. (1998); reprinted with permission.

[6]The term "materials intensity" refers to the quantity of materials used in the production of a good relative to the quantity of other inputs such as capital, labor, energy, knowledge, etc.

Table 12 . Description of A1 and B1 scenarios[a]

A1. Globalization and market-based development	B1. Globalization and social–environmental consciousness
▪ Strong commitment to market-based solutions ▪ High saving and education levels ▪ High rates of investment and innovation in education, technology, and institutions at the national and international level ▪ International mobility of people, ideas, and technology ▪ Energy and mineral resources abundant because of rapid technological change, which both reduces the resources needed and increases the economically recoverable reserves ▪ High incomes translate into high car ownership, sprawling suburbia, and dense transportation networks	▪ Clear evidence that deforestation, soil depletion, overfishing, and global and regional pollution pose a serious threat to human life ▪ Globally coherent approach to more sustainable development ▪ Balanced economic development ▪ World invests in gains from improved efficiency of resource use, equity, social institutions, and environmental protection ▪ Smooth transition to alternative energy sources
Year 2100 projections ▪ Population low (7 billion) ▪ Economic growth very high (2.9%/yr) ▪ Energy use very high (2 226 EJ) ▪ Hydrocarbon use high	Year 2100 projections ▪ Population low (7 billion) ▪ Economic growth high (2.5%/yr) ▪ Energy use low (514 EJ) ▪ Hydrocarbon use low
▪ Oil: 20.8 ZJ ▪ Gas: 42.2 ZJ ▪ Coal: 15.9 ZJ ▪ Land-use change low	▪ Oil: 19.6 ZJ ▪ Gas: 14.7 ZJ ▪ Coal: 13.2 ZJ ▪ Land-use change high
▪ Forests: +2%	▪ Forests: +30%

[a]Source: Nakicenovic and Swart (2000).

The A2 and B2 story lines are the most moderate of the story lines (i.e., the least extreme with respect to projections of climate change) and formed the basis for developing socioeconomic scenarios for Vanderhoof (as described below). They are also the story lines used for the biophysical modeling described in the previous section.

Socioeconomic Scenarios for Vanderhoof

Scenarios are not meant to be predictive. Rather, they are constructed to stimulate thinking about the future. The socioeconomic scenarios for Vanderhoof described in this section are premised on the assumption that global market conditions and climate change are the two major forces that will influence the community's socioeconomic future.

Radar maps are a form of graphic presentation used in scenario development to visually represent different future states on the basis of different combinations of drivers. The radar map shown in Figure 32 combines global market and climate change alternatives for Vanderhoof. The A2 and B2 scenarios form the poles of the climate change scale (the horizontal scale in Figure 32). This scale represents a range of potential change in climate that could occur in the Vanderhoof study area, from a moderate rate climate change (under the B2 emissions scenario) to a higher rate (under the A2 emission scenario).

Strong and weak market outlook conditions form the poles of the market outlook scale (the vertical scale in Figure 32). The continuum ranges from a market outlook that is favorable

Table 13 . Description of A2 and B2 scenarios[a]

A2. Regionalization and market-based development	B2. Regionalization and social–environmental consciousness
▪ Lower trade flows than A1 and B1 ▪ Relatively slow turnover of capital stock and slower technological change ▪ Consolidation into a series of economic regions ▪ Self-reliance in terms of resources and less emphasis on economic, social, and cultural interactions between regions ▪ Uneven economic growth; income gap remains	▪ Government policies and business strategies influenced by environmentally aware citizens ▪ International institutions decline in importance, with a shift toward local and regional decision-making structures and institutions ▪ Relatively slow rate of development, with technology adoption varying by region ▪ Environmental protection is one of the few truly international common priorities ▪ Favorable climate for community initiatives and social innovation, given high education levels ▪ Gradual decrease in reliance on hydrocarbons
Year 2100 projections ▪ Population high (15 billion) ▪ Economic growth medium (2.3%/yr) ▪ Energy use high (1 717 EJ) ▪ Hydrocarbon use high ■ Oil: 17.3 ZJ ■ Gas: 24.6 ZJ ■ Coal: 46.8 ZJ ▪ Land-use change medium ■ Forests: 0%	Year 2100 projections ▪ Population medium (10 billion) ▪ Economic growth medium (2.2%/yr) ▪ Energy use medium (1 357 EJ) ▪ Hydrocarbon use medium ■ Oil: 19.5 ZJ ■ Gas: 26.9 ZJ ■ Coal: 12.6 ZJ ▪ Land-use change medium ■ Forests: +5%

[a]Source: Nakicenovic and Swart (2000).

to the Vanderhoof economy (or that has provided opportunities advantageous to the Vanderhoof economy) to one encompassing global socioeconomic trends and futures that are unfavorable to the Vanderhoof economy. For example, a strong market outlook results from high commodity prices, stable or increasing export demand, and locally competitive firms. Conversely, unfavorable market conditions would result from low commodity prices, unstable or decreasing export demand, and the presence of unproductive and/or high-cost producers in the local economy.

Four socioeconomic scenarios were developed for Vanderhoof, represented by the four quadrants on the radar map shown in Figure 32. The upper left quadrant of Figure 32 describes a future in which climate change is moderately low and market conditions are favorable for the industries located in Vanderhoof. Under this scenario, Vanderhoof is a highly attractive location in which to conduct business and a desirable community in which to reside. The local economy has diversified through a combination of high regional capacity and regional investment. The positive economic atmosphere is facilitated and driven by a governance and policy framework promoting regional technological development and adoption, with a focus on environmental considerations (i.e., reduction of GHG emissions). Profitability is high because firms are producing products for which Vanderhoof has a distinct advantage and for which its businesses are able to capture markets. The economy is healthy and likely better able to respond and adapt to local impacts of climate change – expected to be relatively minor in any case – than with any of the other socioeconomic scenarios.

The upper right quadrant of Figure 32 describes a future in which climate change is moderately high and market conditions are favorable for the industries located in Vanderhoof. Commodity-driven economic growth is more important than reductions in GHG emissions, and technological change focuses more on improving productivity than on developing alternative technologies and new products. The economy is commodity driven, but is somewhat more diverse than in the previous scenario, as a result of success in attracting new investment (through a business-friendly investment climate, high profitability, and an emphasis on open markets). Local climate impacts may be significant; however, the strong economy and the underlying economic fundamentals that have resulted (i.e., entrepreneurship, innovativeness, and business-friendly institutions) increase community resilience and economic adaptive capacity.

The lower left quadrant describes a future in which climate change is moderately low and market conditions are unfavorable. Global commodity demand is depressed because of environmental reforms focused on reducing energy use and GHG emissions. Alternative energy technology is being adopted, but Vanderhoof is lagging behind other regions and has not seen the benefit of regional investment and technological development. As a result, economic diversity is relatively low and profitability marginal. Market solutions are not a dominant focus, and the governance structure is ineffective in reducing barriers to adaptation. Vanderhoof lags behind other regions of the world in investment and development of alternative technologies. Community resources available for adapting to climate change are limited, mainly because these resources are fully engaged in addressing other social and economic development issues and pressures. However, the magnitude of climate change is expected to be low, so additional demands on community resources for adapting to climate change are also low.

The lower right quadrant of Figure 32 describes a future in which climate change is moderately high and market conditions are unfavorable. Investment and technological advancement in other regions of the world are outpacing those in Vanderhoof and, despite a market-driven focus, profitability and economic diversity are low. Investment and technology remain focused on commodities, but the unfavorable global conditions are depressing both commodity prices and the local economy, resulting in local unemployment and stagnant growth. Moreover, climate change is increasing the global supply of forest and agricultural products, which is in turn increasing competitive pressures on Canadian producers. Local climate impacts are potentially significant and the need for adaptation is therefore high. However, the capacity to adapt to the impacts of climate change is low because resources are fully employed in addressing other pressing social and economic development issues.

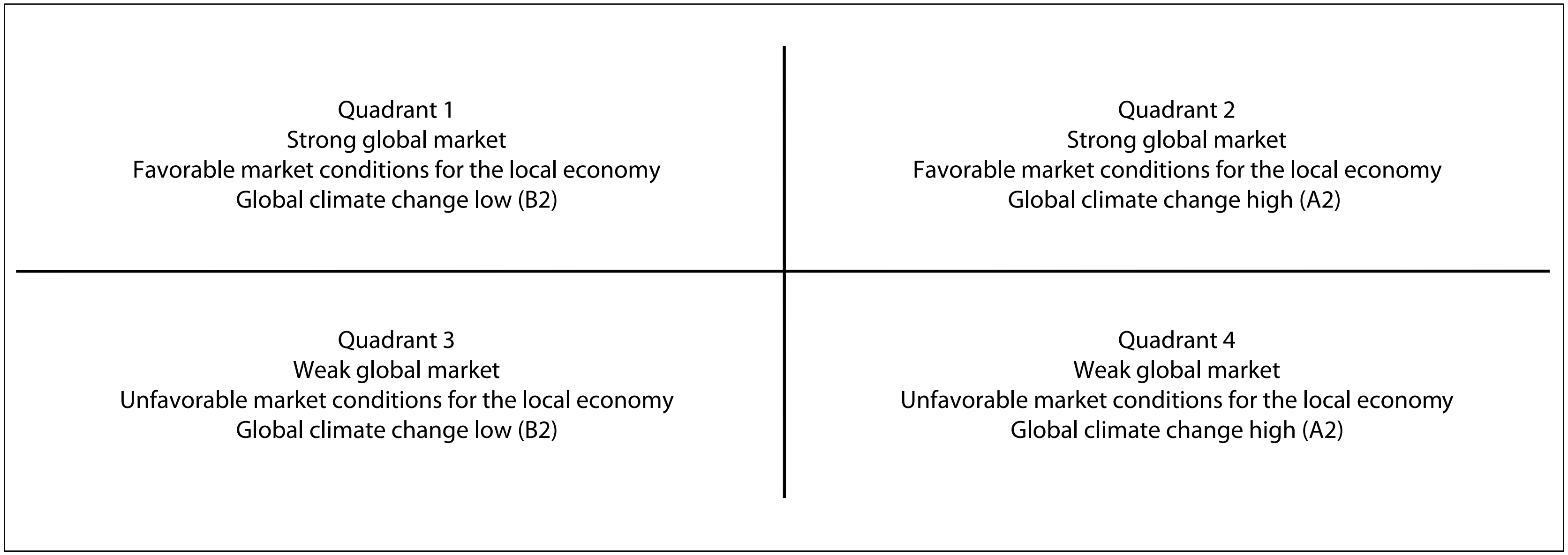


Figure 32. Four potential scenarios of global market and climate change with implications for local resource-based economies. A2 = scenario with a regionalized global economy in which the rate of increase in greenhouse gas emissions is comparable to the rate of increase in the 1990s. B2 = scenario with a regionalized global economy in which societies are more socially and environmentally conscious than in scenario A2, with slower population growth, lower energy intensity, and less reliance on fossil fuels, leading to a much lower rate of growth in greenhouse gas emissions.

Potential Impacts of Climate Change on Global Markets for Forest Products

Climate change may result in changes in the global supply of many renewable resource-based commodities (e.g., agricultural products and forest products). Firms in resource-based communities export their products to global markets, so increases in supply from firms in competing countries may have downstream impacts on firms in resource-based communities in Canada. Canada is currently the world's leading exporter of forest products, and British Columbia is Canada's leading province in this respect. Therefore, one area in which British Columbia's forest-based communities may be vulnerable to climate change is its export-based forest economy, which could be affected by long-run structural change in global markets for forest products.

Recent analysis has suggested that climate change will increase the global timber supply (Sohngen and Sedjo 2005). This increase will be unevenly distributed, higher in some regions (e.g., South America and New Zealand) and lower in others (e.g., North America), which will result in a realignment of comparative advantage in the various producing regions. More generally, there will be gains to consumers (in the form of dampened prices) and changes in trade patterns for forest products (Sohngen and Sedjo 2005). These trends have important implications for producers in exporting countries like Canada. For example, Sohngen and Sedjo (2005) found that the real prices faced by producers in North America will likely decline under climate change and that producers' surplus (total sales revenues in excess of marginal costs at points along a firm's supply curve) could decline by up to $2 billion per year over the next century.

Perez-Garcia et al. (2002) used transient climate scenarios linked to an ecological model (the Terrestrial Ecosystem Model), which was in turn linked to the CINTRAFOR Global Trade Model (University of Washington), in modeling the impacts of climate change on the global forest sector. They found that the market impacts of climate change up to 2040 would be generally negative and significant for Canadian producers. In fact, economic losses to Canadian producers were projected to be higher than for any other producing region. The results of this study were not specific to the British Columbia forest industry or the Vanderhoof economy. However, given that British Columbia is Canada's largest exporter of forest products, its economy may be vulnerable to global market restructuring. Thus, market-related impacts of climate change on the provincial forest industry (and quite possibly the Vanderhoof economy) could be significant. An important consideration, however, is that the impacts are predicted to occur over a long period. Moreover, the predicted structural changes will occur alongside a host of other changes that are simultaneously affecting the forest sector, for example, population change, technological change, changes in tariff and nontariff trade barriers, changes in input prices and costs, trade disputes, changes in exchange rates and interest rates, and changes in consumer tastes and preferences. It may therefore be difficult to distinguish the effects of climate change from those of other market factors and correspondingly difficult to develop and implement adaptation measures that respond specifically to climate change considerations. It is reasonable to assume that climate change will occur in tandem with other factors affecting Canada's ability to compete in the global market and that climate change may exacerbate the negative implications of these trends for Canadian producers. Canada has relatively high labor costs and high wood input costs. The country's market share in traditional commodity lines has, in some cases, already started to decline for reasons unrelated to climate change. However, the countries that are replacing Canadian products in the global market are those expected to be significant beneficiaries of climate change from a production standpoint (i.e., South America and Oceania). Consequently, climate change may increase the vulnerability of Canada's share of the global export market for traditional commodities. Adaptation in this context would involve considering the combined impacts of climate change and other market factors in developing strategies to reduce exposure to structural changes in traditional commodity lines. It may also require increasing the adaptive capacity of Canadian firms by identifying, removing, and/or reducing institutional barriers that limit Canada's ability to adapt and compete in global markets. Some specific areas that have been proposed include taking measures to develop new value-added products, developing specialized niche markets, improving efficiency, reducing costs, and increasing the role of economic markets in facilitating adaptation. Each of these proposals will require a strong commitment to technology development, innovation, and institutional reforms (including forest-related policies).

Sensitivity of the PGTSA Economy to the Impacts of Climate Change on Regional Forest Resources

Vanderhoof's primary industry is the forest industry, which relies on local forests as its main source of raw material. The analysis presented in the section entitled "The Climate of the Vanderhoof Study Area" showed that forest ecosystems in the vicinity of Vanderhoof will be affected by future changes in climate. Changes in species composition, forest productivity, and fire frequency are likely to affect timber supply over the medium to long term. Moreover, short-term projections in the wake of the MPB outbreak indicate inevitable changes in harvest rates over the next two decades. Hence, climate change has the potential for short-, medium-, and long-term impacts on the economy of Vanderhoof as a result of changes in timber supply.

This section provides an analysis of these various effects on the economy of the PGTSA. The approach draws on the Can-IBIS model outputs described earlier in this report. One of these outputs is increment in softwood stemwood (reported as kilograms of carbon per square meter per year but converted to cubic meters of carbon per hectare per year using linear conversion factors). Estimates of future stemwood increment were divided by estimates of stemwood increment under current climate conditions to estimate productivity multipliers (see Figure 33). These multipliers were then used to adjust existing timber supply estimates to generate scenarios of possible future timber harvest under alternative climate scenarios (described in detail in the later section entitled "Simulations of Effects of Climate Change on Future Harvest Potential"). The current and future timber harvest scenarios (with and without climate effects) were then linked to an existing computable general equilibrium (CGE) model of the PGTSA economy to estimate impacts on household income (see Patriquin et al. [2005] and Appendix 5 for an overview of the CGE model used in this study).

Two climate-related factors were considered in combination in the economic impact analysis presented here: the MPB outbreak and the possible medium- and long-term impacts of future climate change on growth. All other exogenous determinants were held constant. The purpose of this analysis was to determine the outlook for potential future timber harvest under various climate change scenarios. As such, these are not measures of annual allowable cut (AAC) but rather crude estimates of future harvest possibilities and impacts on timber supply based on modeling. Also, a number of simplifying assumptions form part of the analysis. The caveats and assumptions for this analysis are discussed later in this section.

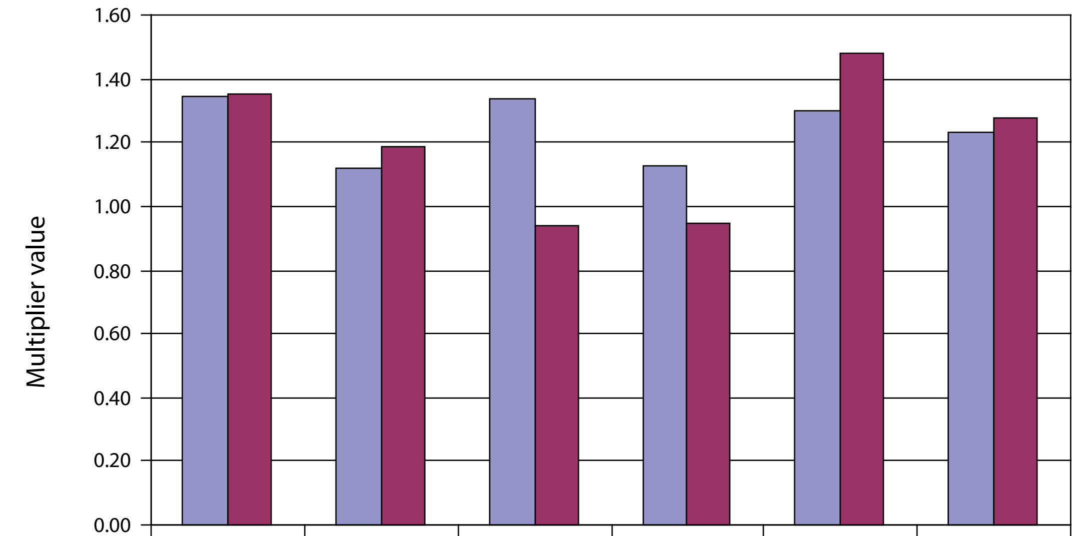
Prince George Timber Supply Area

As noted in the description of the study area, Vanderhoof is located within the PGTSA, which comprises three forest districts: the Prince George Forest District, the VFD (described earlier), and the Fort St. James Forest District. The boundaries for these districts correspond to the three similarly named Land and Resource Management Plan areas (see Figure 6).

The PGTSA has a total area of about 7.5 million ha, of which 5.33 million (71%) is provincial crown forest. Approximately 61% of the crown forest lands are potentially available for harvesting (Pedersen 2004). The distribution of tree species on the harvest land base is as follows: pine stands account for 51% of forest cover (around 80% in the VFD), spruce stands for about 31%, subalpine fir for about 16%, and other species (Douglas-fir, cedar [*Thuja* spp.], hemlock [*Tsuga* spp.]) for the remaining 2% (Pedersen 2004).

Current AAC and Future Harvest Scenarios without Climate Change

As noted above, the majority of forest lands in the PGTSA are under public ownership. Harvesting on these lands is regulated through the establishment of an AAC by the BCMOFR.



	CGCM2–A2	CGCM2–B2	CSIRO Mk2–A2	CSIRO Mk2–B2	HadCM3–A2	HadCM3–B2
50 years	1.34	1.12	1.34	1.13	1.30	1.23
100 years	1.35	1.19	0.94	0.95	1.48	1.28

Scenario

Figure 33. Stemwood productivity multipliers in 50 and 100 years, determined by the Canadian Integrated Biosphere Simulator for the Vanderhoof study area under the various climate scenarios. CGCM2 = Canadian Second-Generation Coupled Global Climate Model; CSIRO Mk2 = Commonwealth Scientific and Industrial Research Organization Mark 2 model; HadCM3 = Hadley Centre Third-Generation Coupled Model; A2 = scenario with a regionalized global economy in which the rate of increase in greenhouse gas emissions is comparable to the rate of increase in the 1990s; B2 = scenario with a regionalized global economy in which societies are more socially and environmentally conscious than in scenario A2, with slower population growth, lower energy intensity, and less reliance on fossil fuels, leading to a much lower rate of growth in greenhouse gas emissions.

The ministry's chief forester takes multiple factors into account in determining the AAC, which is regularly revised and updated. The AAC is not intended as a target harvest level, fixed in perpetuity. However, one of the reasons for setting the AAC is to ensure the sustainable management of forests. Therefore, an important factor in determining the current AAC is the long-term future timber supply (i.e., estimates of potential timber supply over a 200-year planning horizon, given a particular current AAC).

The main tree species in the PGTSA (and the VFD) is lodgepole pine, the predominant host species for the MPB. The widespread mortality caused by the recent MPB outbreak has led to significant revisions in AAC for the VFD and the PGTSA as a whole (Figures 34 and 35). These revisions have been mainly in the form of temporary AAC uplifts, to permit salvage of beetle-killed pine stands and thus to limit spread of the outbreak (Pedersen 2004). Figures 34 and 35 were reconstructed from data provided in the chief forester's 2004 AAC determination for the PGTSA (Pedersen 2004). In the mid-1990s, the AAC for the PGTSA was around 9.4 million m^3. It was increased to 12.2 million m^3 in 2002 and then to 14.9 million m^3 in late 2004 to allow salvage of beetle-killed timber. The relative shifts in AAC in the VFD have been even more dramatic, because of the relatively higher proportions of pine in the Vanderhoof forest. In the mid-1990s, the AAC for the VFD was approximately 2.0 million m^3. It was increased to 3.8 million m^3 in 2002 and then to 6.5 million m^3 in late 2004. Over the next 15 years, as the beetle-killed pine is salvaged or is lost through degradation, the AACs for the PGTSA and VFD will be decreased.

In addition to the temporary uplifts in AAC, the widespread loss of a major portion of the living forest will have other implications for long-term timber supply. The MPB outbreak has now become widespread. Even pine trees in younger age classes are at risk, as is most of the mature pine forest in the PGTSA. The impact on long-term timber supply depends on how much timber is killed before the outbreak subsides. In 2004, the BCMOFR calculated a base-case future potential timber supply based on expected levels of cumulative mortality up to the year 2005. They also derived an alternative timber supply forecast based on the assumption that the beetle outbreak would continue until 2010.

Figure 34 shows these two scenarios (base-case and alternative) for future potential timber supply without future climate change effects. The base-case scenario assumes a decrease in harvest potential in the PGTSA to a level of 7.9 million m^3 yr^{-1} by 2015. For the VFD, the fall-down in long-term harvest (compared with historical AACs) is even more drastic. The AAC for the VFD was around 2 million m^3 yr^{-1} in 2000, but the long-term projected annual harvest is 1.6 million m^3 yr^{-1} (Figure 35).

Under the BCMOFR's alternative projection for timber supply (assuming that the beetle outbreak will continue until 2010), a total of 171 million m^3 of merchantable pine on the harvest land base will be killed by 2010 (Pedersen 2004). This would have significant implications for long-term supply and the magnitude of timber supply "fall-downs." The long-term harvest potential would decrease to 7.4 million m^3 yr^{-1} (Figure 34); for the VFD, the long-term annual harvest potential decreases to under 1 million m^3 (Figure 35).

Simulations of Effects of Future Climate Change on Stemwood Productivity

The MPB outbreak is the result of a number of interconnected factors, including a sequence of relatively warm winters, which have lacked the sustained cold temperatures required to kill overwintering beetles (Carroll et al. 2004). Thus, the outbreak may be, at least in part, the consequence of a climate that has already started to change.

However, the MPB outbreak is only one of the ways in which climate change may affect forests and timber supply in the VFD. As discussed earlier, understanding the cumulative impacts of climate change on timber supply requires a linkage between scenarios of future climates and models estimating how forest productivity and growth may be affected. This section describes the approach used for projecting the effects of future possible climates on forest productivity for the study area.

Can-IBIS was used to model the effects of climate change on future stemwood productivity for the Vanderhoof study area. As noted above, one output from this model is increment in softwood stemwood. For the purposes of this study, this variable was used as a proxy for annual growth within the study area. Softwood stemwood increment in the study area for each year in the period 2001–2100 was modeled for six climate scenarios (as described in the section entitled "Climate of the Vanderhoof Study Area").

Predictions of annual stemwood increments for the next 100 years for all six scenarios and corresponding trend lines (based on quadratic equations, estimated by fitting curves to annual projections of stemwood increment) are provided in Appendix 4. The estimated quadratic equations were then used to predict current stemwood increments in 50 and 100 years (power functions were also estimated, but values for the coefficient of determination [R^2] indicated that the quadratic polynomials provided a better fit to the data). Future increment was divided by current increment to derive growth multipliers (Figure 33). The best-case scenario in 50 years occurred with the CSIRO Mk2–A2 scenario, under which Can-IBIS predicted that stemwood increment in 50 years would be about 34% higher than current growth. The worst-case scenario occurred with the CGCM2–B2 scenario, under which Can-IBIS predicted that stemwood increment would be about 12% higher than current growth.

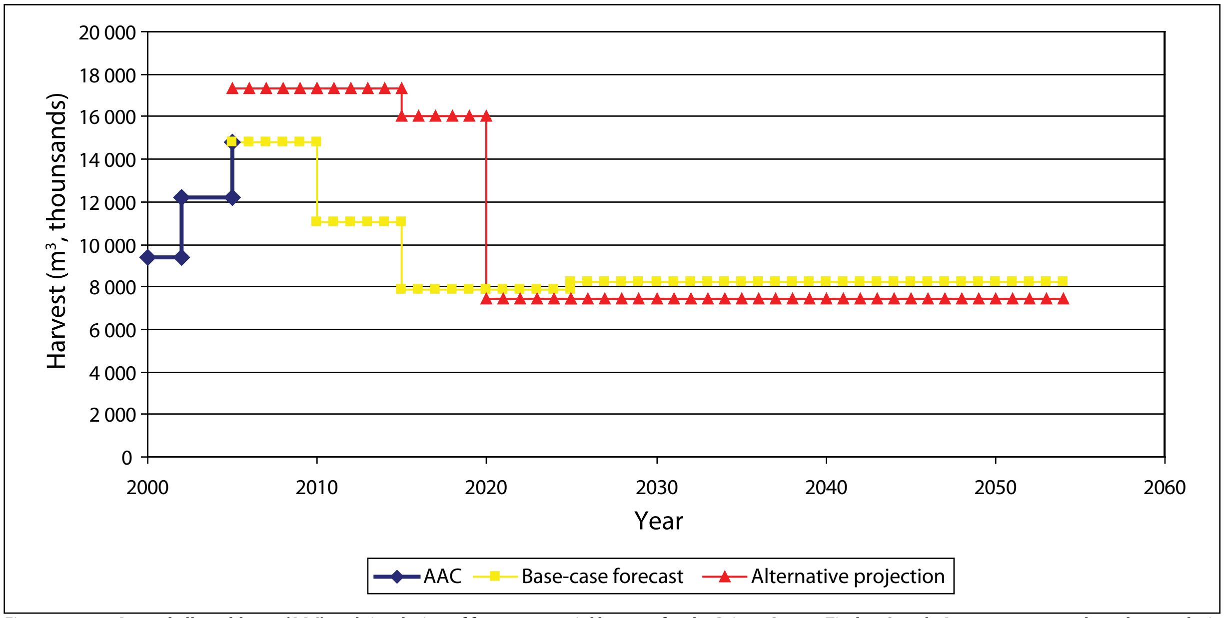


Figure 34. Annual allowable cut (AAC) and simulation of future potential harvest for the Prince George Timber Supply Area, 2000–2055, based on analysis conducted by the BC Ministry of Forests and Range in 2004. Data points obtained from Pedersen (2004).

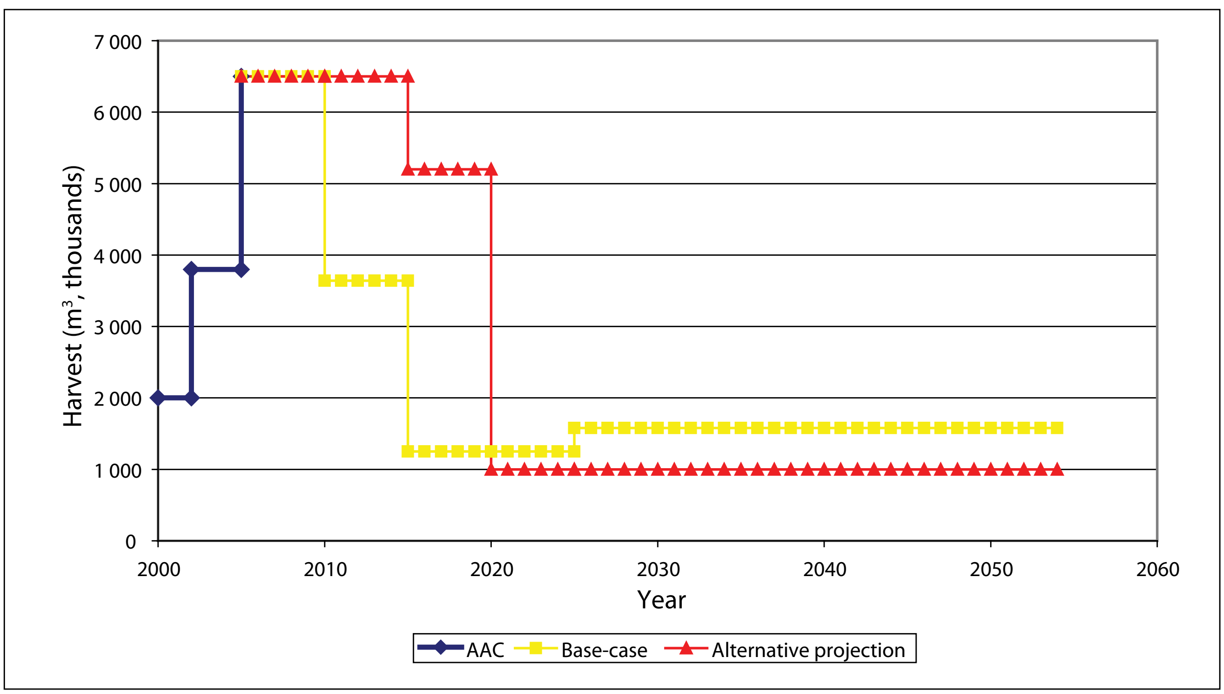


Figure 35. Annual allowable cut (AAC) and simulation of future potential harvest for the Vanderhoof Forest District, 2000–2055, based on analysis conducted by the BC Ministry of Forests and Range in 2004. Data points obtained from Pedersen (2004).

Simulations of Effects of Climate Change on Future Harvest Potential

The BCMOFR timber supply forecasts for the PGTSA and the VFD consider two MBP impact scenarios but do not account for the effects of future climate change on growth. The next step was to use the growth multipliers (described above) to adjust the BCMOFR forecasts. First, timber supply in the year 2054 was determined by multiplying the BCMOFR estimates of long-term supply (i.e., timber supply after all fall-downs come into effect) by the best-case and worst-case growth multipliers for 50 years hence (1.34 and 1.12, respectively). These calculations assume a direct one-to-one relation between growth and annual supply. Thus, if growth is projected to increase by 34%, then annual supply would also increase by 34% (and mean annual increment = AAC).[7] The difference in growth rate between the harvest rate immediately after the post-beetle fall-downs and the potential harvest in the year 2054 was assumed to be linear.

The combination of two beetle scenarios (best- and worst-case effects of beetle-caused mortality) with two climate scenarios (best- and worst-case growth effects) resulted in four possible trajectories for timber supply in the VFD and in the PGTSA as a whole:

Scenario 1: best-case beetle and best-case climate (CSIRO Mk2–A2)

Scenario 2: worst-case beetle and best-case climate (CSIRO Mk2–A2)

Scenario 3: best-case beetle and worst-case climate (CGCM2–B2)

Scenario 4: worst-case beetle and worst-case climate (CGCM2–B2)

The results for these scenarios are shown in Figure 36, for the PGTSA and Figure 37, for the VFD. Generally, climate change is predicted to have a positive effect on growth rates and annual supply up to the year 2054. Under scenario 1, annual supply in 2054 could be somewhat higher than the prebeetle AAC for the PGTSA (point G, Figure 36). However, under scenario 4, whereby the beetle outbreak does not subside and the least favorable climate scenario occurs, the PGTSA timber supply in 2054 could be somewhat lower than prebeetle AACs (i.e., 8.3 million m^3 rather than 9.4 million m3) (point J, Figure 36).

The impact of the MPB outbreak on future timber supply is more pronounced in the VFD because of the more significant representation of pine. Moreover, even with positive growth effects under future climate change, annual supply is not expected to recover to prebeetle levels. At best, supply in 2054 may be 84% of the prebeetle AAC. For the worst-case combined scenario (scenario 4), annual supply in 2054 would be 53% of the prebeetle AAC.

It is also possible to assess the potential effects of climate change on supply over the long term, which refers to the period 2054–2100. The growth multipliers predicted by Can-IBIS for the period around 2100 (Figure 33) represent projections of the change in growth rates in the year 2100 relative to current growth rates. Four of the scenarios (CGCM2–A2, CGCM2–B2, HadCM3–A2, and HadCM3–B2) result in growth responses similar to or slightly higher than the growth responses predicted for 2050. For the CSIRO Mk2–A2 and CSIRO Mk2–B2 scenarios, growth is projected to be lower than current forest growth.

One general conclusion that can be drawn from these results is that, over the next 50 years, climate change will have a positive impact on growth and timber supply in both the PGTSA and the VFD. These positive growth effects might offset some of the losses experienced as a result of the recent MPB outbreak in the PGTSA, but not in the VFD. Overall timber supply will likely remain below the prebeetle AAC for the next 50 years, even with positive effects of climate on growth rates.

Another conclusion is that climate change may contribute to increased uncertainty and instability in the timber supply, leading to either increased or reduced growth rates. Communities

[7]It is assumed that changes in growth rates as a result of changes in forest structure are reflected in BCMOFR projections of potential future harvest. However, the effects of changes in forest structure resulting from the MPB outbreak are not reflected in the projections of incremental changes in growth rates due to climate change obtained from the Can-IBIS model.

should therefore not assume that future timber supplies will be stable or certain. Local timber supply may also be affected by changes in disturbance patterns. As noted in the previous section, the risk of fire in the study area is expected to increase by the period 2040–2060 (according to the analyses of fire risk with the BURN-P3 model); of note, the increase in fire risk suggested by Can-IBIS is relatively modest compared with that of the BURN-P3 model, which suggests that Can-IBIS is overestimating growth responses. Early awareness and planning may be beneficial so that communities can prepare for and manage the risk associated with increased uncertainty and potential instability in future timber supply.

The analysis presented in this section applies a complex model of ecosystem processes to project the long-term effects of climate change on forest growth and potential harvest in the Vanderhoof study area, the VFD more generally, and the PGTSA as a whole. An important caveat is that although the methods for estimating productivity effects are relatively sophisticated, the approach used to translate these effects into timber supply responses is crude, entailing a number of caveats and simplifying assumptions.

The first caveat is that the projections of future growth response are based on results from a model. Although models do provide a way to look at how systems may respond to stimuli, such as a change in climatic conditions, ecosystems are inherently complex and cannot be modeled with precision. Therefore, the outputs of models such as Can-IBIS contain some degree of error.

A simplifying assumption is that there is a one-to-one correlation between relative changes in future harvest potential and relative changes in stemwood increment. This assumption is, in theory, partly justified, since setting the annual harvest at a level equal to mean annual increment will ensure that forest inventory is not reduced. As such, an increase in annual increment would justify an increase in annual harvest. However, the approach employed provides at best a crude approximation of future timber supply response to climate change.

In this study, stemwood increment for the Vanderhoof study area was estimated and the resulting multiplier applied to estimate future harvest potential in both the VFD and the PGTSA. Therefore, another simplifying assumption is that the growth response to climate change will

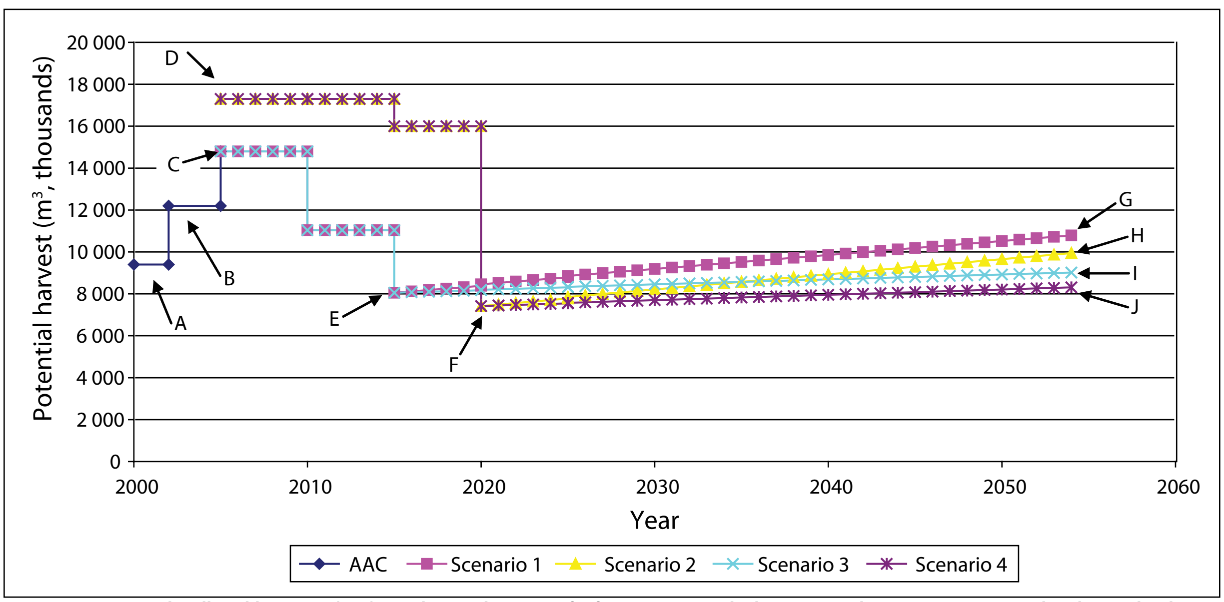


Figure 36. Annual allowable cut (AAC) and simulations of future potential harvest with mountain pine beetle and climate effects for the Prince George Timber Supply Area. Point A is the baseline AAC. Point B is the AAC after the first uplift. Point C is the second uplift (best-case beetle impact scenario). Point D is the second uplift (worst-case beetle impact scenario). Point E is the maximum fall-down under the best-case beetle impact scenario. Point F is the maximum fall-down under the worst-case beetle impact scenario. Point G is the best-case beetle and best-case climate scenario. Point H is the worst-case beetle and best-case climate scenario. Point I is the best-case beetle and worst-case climate scenario. Point J is the worst-case beetle and worst-case climate scenario.

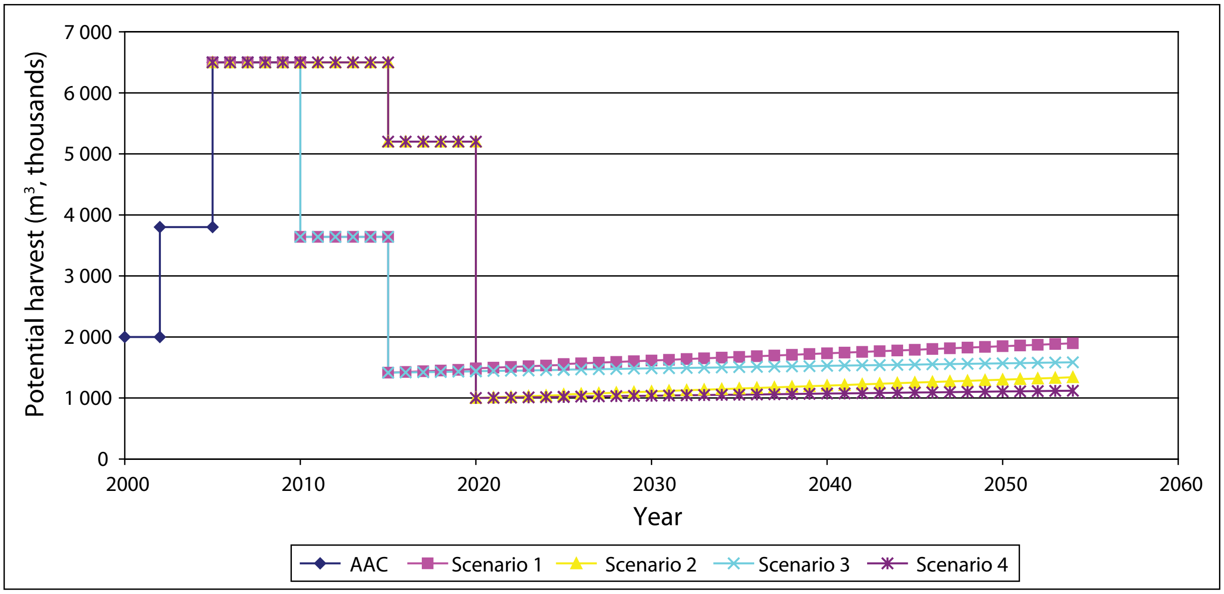


Figure 37. **Annual allowable cut (AAC) and simulations of future potential harvest with climate effects for the Vanderhoof Forest District.** Scenario 1 is the best-case beetle and best-case climate scenario. Scenario 2 is the worst-case beetle and best-case climate scenario. Scenario 3 is the best-case beetle and worst-case climate scenario. Scenario 4 is the worst-case beetle and worst-case climate scenario.

be the same for the three areas (i.e., Vanderhoof study area, VFD, and PGTSA). In reality, this is unlikely, since the forests in these areas are compositionally and structurally different. Moreover, the scale of beetle impact differs. For example, the age-class distribution is likely to change more in the VFD than in the PGTSA because of the higher proportion of pine in the VFD. Nevertheless, the magnitude of change in temperature and precipitation that will be experienced in each of the three areas should be comparable. The growth multipliers, though based solely on the Vanderhoof study area, should be reasonably representative of the other two areas, because the study area encompasses almost all of the VFD and a large portion of the PGTSA (Figure 6).

Economic Impacts of MPB and Climate Change

The previous discussion in this section presents a range of scenario results showing the possible effects of climate change on medium-term timber supply in the PGTSA and the VFD. The next step is to incorporate these results into an economic model to help in understanding the range of local economic impacts. One type of economic model used for this type of analysis is the computable general equilibrium (CGE) model. This type of model is a standard tool 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). The fundamental premise of general equilibrium theory is that the economy is a single system of interconnected parts and every sector is therefore linked to every other sector, whether directly through transactions (purchases and sales) or indirectly through competition for labor, land, and capital used in the production process.

A number of studies have compared CGE modeling in various types of resource-based and forest-dependent regional economies, including Alavalapati et al. (1996, 1999), Marcouiller et al. (1996), Seung et al. (1997), Partridge and Rickman (1998), Alavalapati and Adamowicz (1999), Schreiner et al. (1999), and Patriquin et al. (2002, 2003). All of these studies indicate that CGE techniques can provide valuable information about the potential impacts of changes in natural resource management. They are not commonly applied at a regional scale, but there is general agreement that impact estimates generated from these models are probably less biased than alternative approaches such as input–output models (Alavalapati et al. 1999; Berck and Hoffman 2002).

Patriquin et al. (2005) previously used a Johansen stylized CGE model (Johansen 1974) to estimate the regional economic impacts of the MPB outbreak in the PGTSA. The same model was used for the analysis of economic impacts of climate change and MPB presented in the remainder of this section (see structural details in Appendix 5), so the analysis pertains to the economy of the PGTSA as a whole, rather than Vanderhoof in particular (it is currently not possible to estimate economic impacts for Vanderhoof).

The model specification assumes that the PGTSA economy is small and open, relying on exports. The specific CGE model for the PGTSA contains six sectors (agriculture, forestry, service, public, visitor [tourism], and a composite sector consisting of the "rest of the economy") and three primary factors of production (labor, land, and capital). For the purposes of this study, economic impacts were assumed to occur as a result of changes in timber supply (due to MPB in the short term and climate change in the longer term). However, timber supply is not a direct input to the CGE model. A one-to-one relation between timber supply and forest industry exports from the PGTSA was assumed, such that changes in the economy due to changes in timber supply could be simulated using changes in forest sector exports as a proxy. Trajectories for timber supply were incorporated into the CGE model by changing forest industry exports in direct proportion to the amount of change in timber supply for the PGTSA (i.e., a reduction of a given percentage in timber supply would mean the same percent reduction in exports).

In terms of the three factors of production used in the CGE model, labor is the only input that adjusts to external shocks[8] (such as MPB and climate change); land and capital are fixed within each sector. This assumption of fixed land and capital with climate changes over the next 50 years is a restriction of the model.

The labor market was modeled under two different closure rules. Under the first rule, wages were assumed to be fixed (a significant simplification, particularly for longer-term projections such as those in this analysis). With the fixed-wage assumption, adjustments to the labor market are achieved through changes in employment levels, and unemployment may occur. Under the second rule, wages are flexible and the labor market is always fully employed. In this situation, adjustments to shocks occur through adjustments in labor wages. Adjustments in the labor force are instantaneous, and there is no unemployment (also a somewhat unrealistic assumption). The fixed- and flexible-wage assumptions represent the two extremes of the labor adjustment continuum and probably do not reflect the actual PGTSA economy; however, they are necessary to ensure that the model yields a solution. Thus, the results presented here represent the extremes of labor market impacts, and actual impacts will likely lie somewhere in between.

Economic simulation analysis is a process for examining the economic outcomes of hypothetical changes to current conditions (i.e., scenarios). Its purpose is to inform decision-making by portraying plausible economic outcomes of different management options or external influences before policies are changed or external events unfold. It is important to re-emphasize that the results of these models are not predictions. Rather, the models attempt to roughly identify the direction and order of magnitude of possible impacts.

The usual approach to simulating the economic impacts of natural disturbance or policy options for natural resource management is to translate the output of biophysical models into changes in the factors of production (labor, land, and capital). An alternative, used in the analysis presented here, is to translate the output of biophysical models into expected changes in exports from the economy being modeled. The economic impact of a change in local timber supply is assessed by assuming that forest industry exports change in the same proportion as timber supply (e.g., a change of a given percentage in timber supply results in a change in harvest of the same percentage, which then results in the same percentage change in forest industry exports from the economy under analysis, in this case the PGTSA). This process assumes that domestic demand for timber will

[8]The restriction that limits adjustment to labor is a specific feature of the CGE model. A more complex model could be specified that would allow all three factors of production to vary or that could allow different factors of production to vary simultaneously. The development of such a model was beyond the scope of the current study.

always be satisfied and that any change in timber will result in an equivalent change in forest sector exports.

The simulated changes in harvest levels within the PGTSA between 2000 and 2055 are depicted in Figure 36. For the purpose of the CGE simulation, harvest levels were projected from 10 reference points:

- Point A: baseline AAC level before the MPB outbreak in year 2000 (9.4 million m^3 yr^{-1})
- Point B: first AAC uplift (12.2 million m^3 yr^{-1})
- Point C: second AAC uplift under best-case beetle scenario (14.8 million m^3 yr^{-1})
- Point D: second AAC uplift under worst-case beetle scenario (17.3 million m^3 yr^{-1})
- Point E: maximum fall-down under best case beetle scenario (7.9 million m^3 yr^{-1})
- Point F: maxiumum fall-down under worst-case beetle scenario (7.4 million m^3 yr^{-1})
- Point G: harvest potential in 2055 under best-case beetle and best-case climate scenario (10.8 million m^3 yr^{-1})
- Point H: harvest potential in 2055 under worst-case beetle and best-case climate scenario (9.9 million m^3 yr^{-1})
- Point I: harvest potential in 2055 under best-case beetle and worst-case climate scenario (9 million m^3 yr^{-1})
- Point J: harvest potential in 2055 under worst-case beetle and worst-case climate scenario (8.3 million m^3 yr^{-1})

An important caveat is that the CGE analysis assumes no change in the structure of the PGTSA economy over time. In other words, the impacts simulated for a given change in the region's harvest are in a "with–without" context, independent of any growth, structural adjustments, or new capital investment that might occur over the next 50 years.

Figure 38 shows estimates of the impacts of the various MPB and climate change scenarios on total household incomes within the PGTSA economy. What is apparent from these results is that climate and climate change have the potential for both positive and negative impacts over time. The model estimated that current household incomes in the PGTSA economy would be significantly higher than the base-case level of regional household income. The 4% to 30% increase in household income was largely due to increased economic activity associated with the currently expanded harvest and processing activity associated with salvaging beetle-killed timber. However, between 2015 and 2020, aggregate household income for the PGTSA was estimated to be anywhere from 1% to 7% below household income levels for the year 2000. In the longer term, under conditions of climate change, the Can-IBIS model projected a continuation of forest cover and an increase in forest productivity in the PGTSA. This projected increase in productivity may translate into an increased harvest, increased exports, and an increase in household income that can then be attributed to climate change. In fact, under the best-case climate scenario, aggregate household income for the PGTSA economy could be as much as 5% higher than baseline income, but under the worst-case scenario, it could be 4% below baseline. Thus, there is some ambiguity and uncertainty about the long-term effects. What is important to note, however, is that the forest economy in the PGTSA area can be expected to benefit from climate change over the longer term and that climate change will result in some volatility in the region's economy over the next 50 years.

As noted, the economic model used for this analysis was designed to assess impacts within the PGTSA economy as a whole, of which the Vanderhoof economy constitutes only a part. Although empirical projections for the Vanderhoof economy cannot be provided, inferences can be drawn from Figure 37, which presents scenarios or projections of possible harvest trajectories for the VFD for the next 50 years. This graph suggests that medium-term beetle impacts will be more dramatic in the VDF than in the PGTSA, with higher uplifts and lower maximum fall-downs. In addition, although climate change is predicted to increase productivity in the Vanderhoof region over the long term, harvest rates in the VFD will not recover to prebeetle levels by 2055. Thus, the negative impacts of the beetle outbreak will be felt for at least 50 years after the maximum fall-down. The immediate economic benefits associated with salvage operations, as well

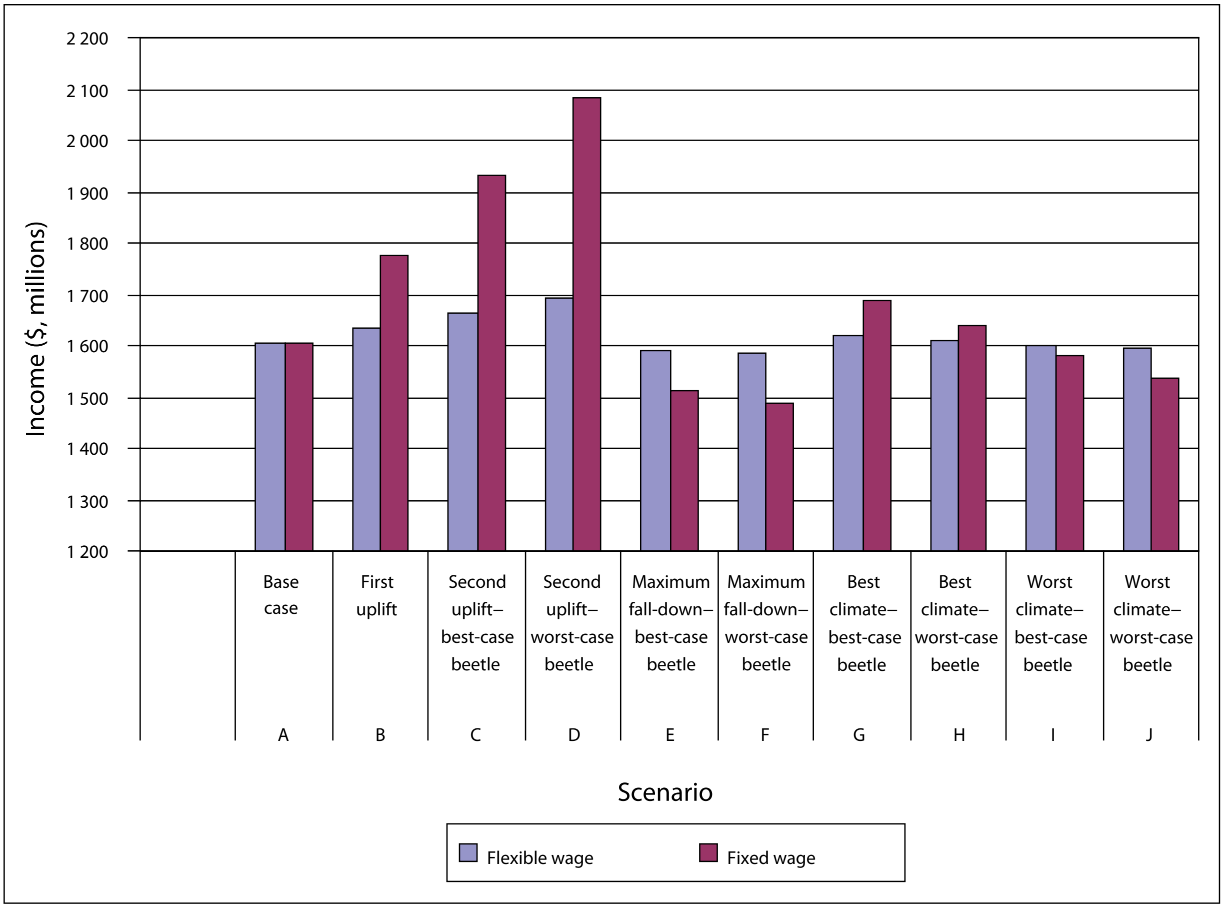


Figure 38. Impacts of climate change on household incomes in the Prince George Timber Supply Area.

as the economic losses during the maximum downturn, may be higher than for the PGTSA as a whole. Therefore, the impacts presented for the PGTSA economy could be magnified within the Vanderhoof economy, and the degree of economic volatility experienced in Vanderhoof could be more pronounced.

Some of the analytical limitations and simplifying assumptions for this analysis were described earlier. Three additional simplifying assumptions should be noted. First, the possibility of an increase in demand (and price) for goods and services produced within the Vanderhoof economy (and the pursuant development of new activities and expansion of existing industries) has not been considered. For example, global, national, and provincial population growth could lead to increases in demands for agriculture products, bioenergy products, and tourism, which could result in economic growth and a new portfolio of economic activities in the PGTSA economy. If economic growth and development in nonforestry sectors were to occur, then the projections of household incomes presented above will underestimate actual values. Second, the possible impacts that might results from restructured global timber markets have not been considered. Analysis of the impacts of climate change on the global market for forest products suggests that Canada may be harmed by impacts on producers (i.e., through decreased exports and lower prices) (Perez Garcia et al. 2002). Perez Garcia et al. (2002) estimated that the Canadian harvest could decrease by as much as 4% by 2040, but there is no way to know whether production in Vanderhoof would decrease by a similar amount, a greater amount, or a lesser amount. However, even if harvests were to decline by 4% within the PGTSA, total household income would likely decrease by only an additional 1.4% under the most rigid of the adjustment assumptions (the fixed-wage adjustment) (since, according to Patriquin et al. [2005], a 1% reduction in forest industry exports leads to a 0.35% reduction in household income under the fixed-wage assumption). Therefore, in isolation, the market impacts of climate change on the PGTSA economy are expected to be small but may be of greater significance when combined with other potential economic stresses. For example, if global demand is flat and Vanderhoof producers are using outdated technology, the significance of increasing global supplies may be relatively more important for the Vanderhoof economy. The third simplification is that the possibility of losses due to increased risk of fire and pests has not been directly considered. The fire analysis in the previous section suggests the possibility of significant intensification of fire susceptibility in the Vanderhoof study area.

Summary

The findings presented in this section suggest that, over the short term, the Vanderhoof economy may experience some volatility and some reduction in household incomes from forest sector employment as a result of MPB. In the medium term (i.e., up to 2054), climate change will likely have some positive economic benefits for the forest industry, but they may not be enough to permit the Vanderhoof economy to recover to levels experienced in the year 2000 (assuming no new investment and assuming that the economy continues to rely heavily on the forest industry). In the long term (i.e., 2054–2100), four of the six models of climate change (forced by the A2 or B2 emissions scenarios) indicated that increases in forest productivity would continue. However, two of the models (CISIRO–A2 and CISIRO–B2) indicated a decrease in forest productivity. Thus, forest productivity may decline under some climate change scenarios. Moreover, many other factors not considered in the Can-IBIS modeling may have significant impacts on productivity and mortality over the longer term, including maladaptation of genotypes, increased risk of fire, increased risk of insect and disease attacks, and increased risk of loss due to extreme weather. The longer-term projections are considerably more uncertain than the medium-term (i.e., to 2050) projections.

Other Possible Impacts

The previous sections of this report have described methodologies for investigating the impacts of climate change on forest ecosystem composition and productivity in the Vanderhoof study area, wildfire susceptibility in the Vanderhoof study area, and the local forest economy. There are numerous other ways that climate change may affect the residents of Vanderhoof, including its impacts on agriculture, water resources, and fisheries. Outdoor recreation and tourism could also be affected (Mendelsohn and Markowski 1999). As noted in the section entitled "Community Overview," water resources, agriculture, fisheries, outdoor recreation, and nature-based tourism are all important in the Vanderhoof region. Quantitative assessment of the impacts of climate change on these values and sectors is beyond the scope of this study. However, given the sensitivity of these areas to climate change, some of the potential implications of climate change are summarized here, along with the general implications of climate change for extreme weather and related incidents. The information in this section is drawn from existing literature, published both in print and on-line and is not specific to Vanderhoof or the surrounding area.

Agriculture

- The impacts of climate change on agriculture vary considerably from location to location.
- Lemmen and Warren (2004) identified a number of potential positive impacts, including increased productivity, possibility of growing crops with higher value, longer growing season, accelerated maturation rates (possibility permitting multiple crop cycles in a single season), and decreased moisture stress.
- Lemmen and Warren (2004) also identified potential negative impacts, including increased frequency of pathogens, crop damage from extreme heat, less reliable forecasting, increased soil erosion, increased weed growth and disease outbreaks, decreased herbicide efficacy, and increased moisture stress and droughts.
- Northern areas and areas currently not limited by moisture are likely to experience the greatest benefit; however, conversion of land to agriculture in response to climate change will be constrained by the availability of suitable soils.

- The impacts of climate change on livestock may include lower feed requirements in the winter; increased calf survival in the winter and possibly reduced overall survival in the summer because of heat waves; reduced productivity, quality, and reproduction due to heat stress; increased production of forage (where moisture is not limited); periodic reductions in forage availability during droughts; and loss of livestock from extreme weather (Lemmen and Warren 2004).
- The IPCC (McCarthy et al. 2001) has noted that the agriculture sector has a very high capacity to adapt to change by shifting crops and methods of production. Furthermore, farmers have significant experience in dealing with climate variability, and the sector overall has a significant institutional capacity to deal with change. Livestock producers may face the largest challenges within the agriculture sector.

Water Resources

- Retreating glaciers
- Reduced snow pack
- Earlier melt of the snowpack
- Earlier timing of peak stream flow in the spring
- Lower stream flow in the summer
- Greater frequency of heavy precipitation events, resulting in increased risk of flooding
- Reduced lake levels in areas where evapotranspiration exceeds precipitation
- Higher water temperatures
- Increased risk of drought
- Increased algae and weed species in freshwater lakes
- Reduced water quality because of increased contaminants in runoff and decreased oxygen concentration in rivers and lakes

Fisheries

- Future changes in fish populations will result from a range of interacting factors, including climate change. Other factors include forest cover along streams and rivers, changes in land use, increases in the withdrawal and use of water by human populations, soil erosion and sedimentation, and the introduction of non-native species.
- Species ranges may move northward, assuming that migration is possible.
- Fish species that prefer warm temperatures (e.g., sturgeon) may benefit from climate change, while cold-water species such as trout and salmon may be harmed (Lemmen and Warren 2004).

Outdoor Recreation and Tourism

- Reduced winter recreation opportunities because of a shorter season
- Benefits in terms of reduced frequency of severe cold snaps resulting in more opportunities for winter recreation activities
- Increased summer recreation opportunities
- Reduced snowfall, with implications for ski hill operations, cross-country skiing, and snowmobiling
- Thinner ice, associated with increased risk of snowmobiles falling through, as well as reduced opportunities for ice fishing and reduced ability for winter roads on the ice surface
- Potential negative impacts associated with diminished forest health and forest esthetics, lower lake levels and river flows, and negatively affected fisheries and wildlife

Extreme Weather

- Climate change may be associated with an increase in extreme weather (e.g., Easterling et al. 2000). For example, weather-related disasters increased significantly in the latter half of the 20th century (Dore 2003).
- Extreme weather includes high winds, heat waves, intense precipitation events, and significant changes in patterns of precipitation (e.g., lengthy periods without precipitation) and/or other weather variables.
- Extreme weather may result in further weather-related disasters, including forest fires, floods, drought, and loss of human life and property.
- For more information, see http://www.ecoinfo.org/env_ind/region/climate/climate_e.cfm.

OVERALL ASSESSMENT OF POTENTIAL LOCAL IMPACTS

A range of methods and approaches for assessing climate impacts at community-relevant scales have been presented and illustrated in this report. New methods and approaches have been introduced and developed in the areas of localized (high-resolution) climate scenarios, assessment of ecosystem impacts, wildfire analysis, socioeconomic scenarios, and analysis of socioeconomic impacts. Previous studies investigating the impacts of climate change on global markets for forest products and the implications for Canadian producers have been reviewed and discussed. The various methodologies have been presented as essentially distinct approaches for dealing with specific types of potential impacts of climate change. This was necessary and useful, because one of the goals of this study was to develop and illustrate new methodologies for assessing climate impacts at community-relevant scales. However, because these impacts will occur simultaneously and because climate change will be occurring alongside broader socioeconomic trends, the assessment of single impacts without context or reference to other impacts of significance to local economies may be of limited value. Communities require assessments that consider combined impacts. An approach is required that permits the results from the analyses of climate scenarios, socioeconomic scenarios, and biophysical and socioeconomic impacts to be considered in a combined way. Moreover, given uncertainty about the outcomes of future climate scenarios, the approach must account for alternative futures and potential impacts under different climate and socioeconomic scenarios. In this section, a modified scenario-based planning structure is proposed as a way of integrating the analyses presented in previous sections into a single overarching assessment. This structure is intended to generate comprehensive scenarios describing the potential impacts of climate change for communities. It has a number of useful features:

- It allows consideration of diverse scientific and technical analyses covering a range of disciplines.
- It provides a straightforward and intuitive way of summarizing the results of complex scientific analysis that is useful to decision makers.
- It allows consideration and integration of multiple sources of information, ranging from scientific analysis, model results, expert judgment, and local knowledge.
- It creates structure for the analysis, so that all types of impacts under any given climate scenario can be compared and contrasted on a comparable basis.
- It accounts for uncertainty by permitting consideration of multiple climatic and socioeconomic scenarios.

The proposed framework for integrating the results of the Vanderhoof case study builds on the radar maps for the socioeconomic scenarios, introduced in the previous section (see Figure 32). The modified framework (Figure 39) differs in having an additional tier. This two-tiered approach reflects the fact that resource-based communities will be affected by socioeconomic and climatic changes occurring at both the global level and the local level. The top layer of the three-dimensional graphic in Figure 39 is the same as Figure 32. It has four scenarios (numbered 1–4) representing different combinations of climate futures (high and low climate change) and socioeconomic scenarios (strong and weak global market). Therefore, the top layer represents four scenarios of possible global changes that may affect resource-based communities, allowing interpretation of these changes in terms of their implications for particular communities. The bottom layer presents four scenarios (numbered 5–8) describing local impacts, which vary depending on local climate exposure (high and low climate change) and local sensitivity to change (high and low expected local impacts). Compressing the two radar maps on the left-hand side of Figure 39 yields the radar map on the right-hand side. This compressed map shows four distinct and comprehensive scenarios of community futures.[9] The approach proposed here serves multiple purposes. First, the two-tiered model

[9]From a vulnerability perspective, however, the scenarios presented in Figure 39 do not represent the complete picture. As noted in the "Introduction," a vulnerability analysis should also include an assessment of adaptive capacity. The integrating framework presented here could be extended by adding a third layer, presenting information about adaptive capacity.

on the left provides a structure for combining potential impacts at multiple scales and offers some transparency regarding the assumptions and technical analyses (scientific and otherwise) that underlie the assessment. The single-tiered radar map on the right is constructed from the two-tiered map, but represents a more concise summary of impacts for use by decision makers.

Four combined scenarios representing socioeconomic and local climate change impacts are proposed for Vanderhoof (Figure 39, Table 14). These community impact scenarios generally apply to a medium-term outlook (i.e., about 2050).

Community Impact Scenario I

Socioeconomic Outlook

Under community impact scenario I, there is a significant increase in the demand for goods and services provided by the Vanderhoof economy through a combination of a high rate of growth in the global economy and the local presence of globally competitive firms. At the same time, countries across the globe have managed to control GHG emissions, so there is less atmospheric forcing, and the rate of climate change is slower than it would have been if nothing had been done. Vanderhoof becomes a highly attractive location for investment because of its combination of a highly skilled local labor force, natural amenities, available natural resources, strong local leadership, and favorable institutional environment. The forest industry continues to be important, but the economy becomes more diversified over time. Global population is projected to reach between 10 billion and 15 billion by 2100, and world economic wealth is increasing. Thus, demand for agricultural products and wilderness tourism opportunities may be increasing.

Climate Outlook

Changes in climate in the Vanderhoof area are relatively minor. Average daily temperature increases by about 0.5 °C by the year 2050 and by about 1.75 °C by 2100 (relative to the year 2000). Average annual precipitation increases marginally from 550 mm (in 2000) to about 575 mm by 2100.

Forest Ecosystem Impacts

The HadCM3–B2 climate and emissions projection was used for the ecosystem analysis for this scenario. The moderate changes in climate are insufficient to trigger large changes in the dominant forest vegetation in the Vanderhoof area by 2100 (see the Can-IBIS projections under the HadCM3–B2 scenarios in this report, in the section entitled “Potential impacts of future climate change on forests in the study area”). By 2050, forest productivity increases by up to 23% because of longer growing seasons and CO_2 fertilization.

Wildfire Susceptibility

The CGCM2–B2 climate and emissions projection was used for the fire analysis for this scenario. In the short term, immediately after beetle-caused tree mortality, there is a significant increase in wildfire susceptibility, but susceptibility declines again once the dead needles drop from the trees. In the longer term, the CGCM2–B2 scenario represents the worst-case climate scenario from a fire standpoint. Under this scenario there is moderate warming but little increase in precipitation, and the area becomes progressively drier, at least until 2050. The result is some increase in fire susceptibility relative to the period before the beetle outbreak and a significant increase relative to the state after the needles have fallen. There is an 82%–118% increase in the proportion of critical fire weather days in the Vanderhoof area and increases of 60% and 59%, respectively, in the area in the high and extreme fire susceptibility classes. There is a moderate increase in the length of the fire season, and the average number of escaped fires (i.e., fires > 20 ha) in the Vanderhoof study area increases from three to five per year.

Forestry-Related Impacts

In the short term (over the next 15 years), the harvest is subject to significant volatility because of initial uplifts for salvage purposes, followed by major fall-downs, which leads to some volatility in the local economy. In the medium term, the lower rate of climate change with community impact scenario I means that climate-related increases in forest productivity are about 23%. This results in smaller harvests, lower production, and fewer exports than might

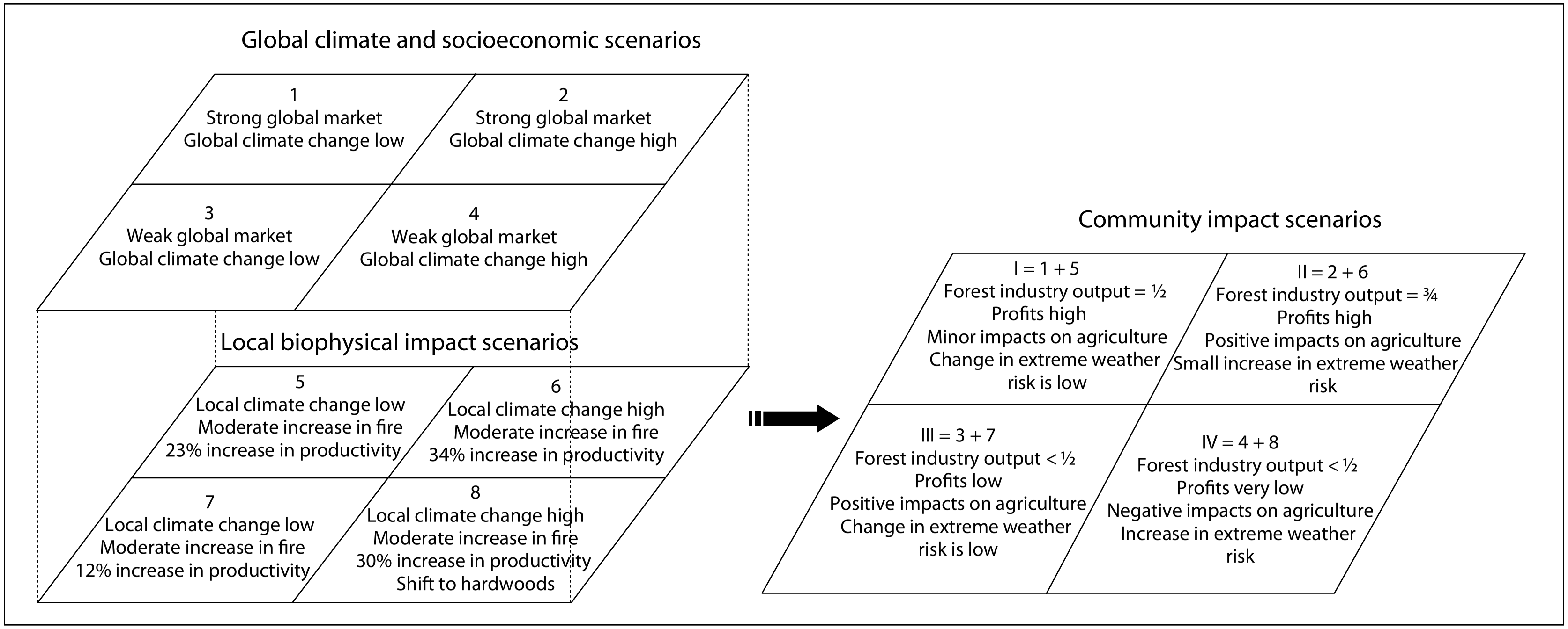


Figure 39. **Example framework, using the Vanderhoof case study, for integrating global climate, socioeconomic, and local biophysical impact scenarios for the purposes of developing community impact scenarios.** The top level of the box on the left provides four scenarios with different combinations of global climate change and global market change. The bottom level of the box on the left provides four scenarios of local biophysical impacts under different assumptions regarding local climate change and sensitivity. The chart on the right compresses the two layers and summarizes community-level impacts. For example, quadrant I on the right is based on the assumed conditions and impact scenarios associated with quadrants 1 and 5 on the left.

Table 14. Impact vectors for Vanderhoof and the Vanderhoof study area for the period 2007 to 2050 using informed community impact scenarios

Impact vector	Scenario I	Scenario II	Scenario III	Scenario IV
Socioeconomic scenarios (2050)				
Global economy	Strong	Strong	Weak	Weak
Local economy	Strong	Strong	Weak	Weak
Local climate change (2050)	Moderate (B2)[a]	Significant (A2)[b]	Moderate (B2)	Significant (A2)
Forest ecosystem impacts				
Species	Minor impacts (HadCM3–B2)[c]	Minor shift (CGCM2–A2)[d]	Minor impacts (HadCM3–B2)	Significant shift to hardwoods (CSIRO2 Mk–A2)[e]
Productivity	Increase by 23%	Increase by 34%	Increase by 12%	Increase by 30%
Wildfire impacts (2050)				
Current	Increased fire due to increased fuels (red state)	Increased fire due to increased fuels (red state)	Increased fire due to increased fuels (red state)	Increased fire due to increased fuels (red state)[f]
Near term	Reduced fire due to reduced fuels (gray state)	Reduced fire due to reduced fuels (gray state)	Reduced fire due to reduced fuels (gray state)	Reduced fire due to reduced fuels (gray state)[g]
Change in proportion of critical fire weather days by 2050	82%–118% increase	31%–111% increase	82%–118% increase	31%–111% increase
Fire susceptibility by 2050	60% and 59% increase in high and extreme fire susceptibility classes in the study area (CGCM2–B2)	Some increase in high and extreme fire susceptibility classes in the study area, but less than under scenario I	60% and 59% increase in high and extreme fire susceptibility classes in the study area (CGCM2–B2)	Some increase in high and extreme fire susceptibility classes in the study area, but less than under scenario III

Table 14. Impact vectors for Vanderhoof and the Vanderhoof study area for the period 2007 to 2050 using informed community impact scenarios (concluded)

Impact vector	Scenario I	Scenario II	Scenario III	Scenario IV
Forest industry impacts (2050)				
Local timber supply potential	Half of year 2000 allowable harvest	Three-quarters of year 2000 allowable harvest	Half of year 2000 allowable harvest	Three-quarters of year 2000 allowable harvest
Global timber supply	Stable	Increasing	Stable	Increasing
Global forest product demand	Strong	Strong	Weak	Weak
Forest product price	Increasing	Flat	Flat	Declining
Key determinants	Timber supply limits production	Flat prices limit investment	Timber supply and flat prices limit production	Possibility of mill closures and/or temporary shutdowns due to declining prices
Local impacts	Profits high but output half of year 2000 levels due to lack of timber	Profits acceptable and output about three-quarters of year 2000 levels	Profits low, timber supply does not increase, output less than half of year 2000 levels	Profits very low, output less than half of year 2000 levels even though timber supply is available
Other climate change impacts				
Agriculture	Minor	Positive	Positive	Longer growing season offset by increased variability
Tourism	Minor	Moderate, negative	Moderate, negative	Significant, negative
Fisheries	Minor	Moderate, negative	Moderate, negative	Significant, negative
Extreme weather	Minor	Small increase	Small increase	Significant increase in risk

[a]B2 = scenario with a regionalized global economy in which societies are more socially and environmentally conscious than in scenario A2, with slower population growth, lower energy intensity, and less reliance on fossil fuels, leading to a much lower rate of growth in greenhouse gas emissions.
[b]A2 = scenario with a regionalized global economy in which the rate of increase in greenhouse gas emissions is comparable to the rate of increase in the 1990s.
[c]HadCM3 = Hadley Centre Third-Generation Coupled Model.
[d]CGCM2 = Canadian Second-Generation Coupled Global Climate Model.
[e]CSIRO Mk2 = Commonwealth Scientific and Industrial Research Organization Mark 2 model.
[f]Red state is where trees have been recently killed and the dead (red) needles remain on the trees.
[g]Gray state refers to the time after the dead needles fall off the trees before significant amounts of new biomass (vegetation and thus fuel) grow in the area.

have been the case if climate change had been more pronounced (e.g., as in community impact scenario II). The allowable harvest in the VFD and forest industry exports are slightly more than half what they were in the year 2000 because of the combined effects of MPB, productivity changes, and wildfire. The forest industry is profitable because of growing demand (and increases in real prices), and it remains an important industry. However, production after the beetle declines does not recover to prebeetle levels. The contribution of the forest industry relative to that of other industrial sectors in Vanderhoof is declining.

Other Impacts

The impacts of climate change on agricultural production, tourism opportunity, fisheries, and water resources are relatively minor. Relative changes in the risk of extreme weather events are small. Population growth and increased global income may increase the demand for agricultural products and wilderness tourism opportunities.

Community Impact Scenario II

Socioeconomic Outlook

The global economy is strong, but the world's nations have not taken the initiative to reduce GHG emissions, and global climate change is therefore significant. Under this scenario, commodity-driven economic growth is emphasized, and environmental protection (at the global scale) is not a high priority. The Vanderhoof economy is strong and growing but remains commodity-based; however, it is somewhat more diverse as a result of new value-added businesses that have been attracted because of the business-friendly climate. A moderately high rate of global climate change has resulted in an increase in global timber supply, but global demand for forest products has increased in direct proportion to this increase in supply, and real prices for these products are flat. Global population is projected to reach between 10 billion and 15 billion by 2100, and world economic wealth is increasing. Thus, demand for agricultural products and wilderness tourism opportunities may be increasing. The Vanderhoof economy fully recovers from the downturns of the mid-2020s, which were caused by the fall-down in local harvest (due to the MPB event) and associated decreases in production in the forest industry. The main sources of growth are industries unrelated to forestry, such as services, agriculture, and tourism, although wood may be used for bioenergy. Under this scenario, the vulnerability of the Vanderhoof economy to climate change (in terms of economic exposure) is moderately low because of the strength of the global economy and the potential for increased productivity in the agriculture and forestry sectors.

Climate Outlook

The change in climate in the Vanderhoof area over the next 100 years is significant. Average daily temperature increases by about 2.5 °C by the year 2050 and by about 4.5 °C by 2100 (both relative to 2000). Average annual precipitation increases from about 550 mm (in 2000) to about 600 mm by 2050 and to 650 mm by 2100.

Forest Ecosystem Impacts

The CGCM2–A2 climate and emissions projection was used for the ecosystem analysis for this scenario. Projected changes to the forest in the Vanderhoof study area are relatively limited, with shifts in species composition to more drought-tolerant conifers (pine, Rocky Mountain Douglas-fir) and increases in hardwood content. Forest productivity increases by up to 34% by 2050 because of longer growing seasons and CO_2 fertilization.

Wildfire Susceptibility

The CGCM2–A2 climate and emissions projection was used for the fire analysis for this scenario. By 2050, there is a 31%–111% increase in the proportion of critical fire weather days during the fire season. The total area with high or extreme fire susceptibility increases to some extent, but is still smaller than under community impact scenario I. The potential for even more significant increases in fire risk is negated by the higher precipitation by 2050 in the CGCM2–A2 scenario relative to the CGCM2–B2 scenario.[10] The amount of global warming is higher than in community impact scenario I. The fire season becomes longer than what is expected

[10]For the period around 2050, the CGCM2 scenarios are drier (projecting lower precipitation) than the HadCM3 and CSIRO2 models.

under scenario I, but conditions are not as dry. Thus, the average number of escaped fires (i.e., > 20 ha) in the study area increases from three to four per year.

Forestry-Related Impacts

The worst-case beetle scenario occurs, and harvests in the Vanderhoof study area reach the maximum fall-down around 2020. After 2020, however, harvesting opportunities increase because of climate-induced increases in the productivity of the remaining forest. However, the costs for delivered wood may also increase as a result of reduced opportunities for winter harvest. The supply of forest products from other countries into global markets increases significantly, but growth in demand keeps pace, and real prices remain flat. Thus, the local forest industry remains profitable, and forest industry exports in 2050 are approximately 75% of 2000 levels (after MPB, productivity, and wildfire effects on local supply are taken into account). Increased global timber supply caused by global climate change is a source of vulnerability for forestry producers in the Vanderhoof area, a problem that is offset to some degree by increased productivity of the region's forests.

Other Impacts

The Vanderhoof agriculture sector benefits from increased food demand (due to increased global population and increased world income), better growing conditions (a longer growing season, more precipitation, and CO_2 fertilization), and the ability to adapt quickly to changing environmental conditions. There is a reduction in forest aesthetics during periods of transition from one forest type to another. Water temperatures increase, which reduces salmon and trout populations. Winters are shorter and milder, and summers are longer. The snowpack is reduced, spring runoff occurs earlier, and summer flow rates are reduced. There is a general reduction in old-growth forest and in the population levels of species with large home ranges and those that prefer relatively pristine forest settings (such as caribou and grizzly bear); conversely, however, ungulate populations may increase. Precipitation may increase through the more frequent occurrence of intense storm events, leading to the possibility of increased risk of flooding. There may be an increased risk of other forms of extreme weather (e.g., droughts, heat waves, and severe storm activity). The potential for change in the landscape surrounding Vanderhoof is a source of vulnerability for tourism operators in the area.

Community Impact Scenario III

Socioeconomic Outlook

In the short term, the local economy experiences some economic volatility because of MPB-related uplifts and fall-downs. In the medium- to long-term, community impact scenario III describes a future in which the extent of climate change is moderately low, but growth in global markets is weak and global market conditions are unfavorable to the Vanderhoof economy. Under this scenario, global commodity demand is depressed because of measures taken to reduce energy use and emissions. Alternative energy technology is being adopted, but Vanderhoof has not kept pace with other regions in terms of implementing the new technology and attracting regional investment. As a result, economic diversity is relatively low and profitability marginal. Despite relatively high local adaptive capacity, the region has been ineffective in reducing barriers to adaptation, which has in turn constrained the implementation of appropriate adaptive responses. Climate change is not a source of vulnerability to the local economy, but general economic conditions may be.

Climate Outlook

Changes in climate in the Vanderhoof area are relatively minor. The average daily temperature increases by about 0.5° by the year 2050 and by about 1.75° by 2100 (both relative to 2000). Average annual precipitation increases marginally by 2050 and to about 575 mm (from 550 mm in 2000) by 2100.

Forest Ecosystem Impacts

The HadCM3–B2 climate and emissions projection was used for the ecosystem analysis for this scenario; however, forests were assumed to be less sensitive than under community impact scenario I. The moderate changes in climate are insufficient to trigger large changes in the dominant forest vegetation in the Vanderhoof area by 2100. Forest productivity increases by a relatively modest 12% under this scenario. (Note that this 12% value is assumed, not derived. The HadCM3–B2 scenario actually projects a 23% increase in productivity by 2050, but the value of the productivity increase has been scaled down for the purposes of this community impact scenario to reflect the assumption of lower forest sensitivity).

Wildfire Susceptibility

The CGCM2–B2 climate and emissions projection was used for the fire analysis for this scenario. In the short term, immediately after beetle-caused tree mortality, there is a significant increase in wildfire susceptibility, but susceptibility declines again once the dead needles drop from the trees. In the longer term, the CGCM2–B2 scenario represents the worst-case climate projection from a fire standpoint. There is moderate warming but little increase in precipitation, and the area becomes slightly drier. The result is some increase in fire susceptibility relative to the period before the beetle outbreak, and a significant increase relative to conditions after the needles have fallen. There is an 82%–118% increase in the proportion of critical fire weather days in the Vanderhoof area, and increases of 60% and 59%, respectively, in the proportion of the study area in the high and extreme fire susceptibility classes. The length of the fire season increases, and the average number of escaped fires (i.e., > 20 ha) doubles from three to six per year.

Forestry-Related Impacts

In the short term (over the next 15 years), local harvest rates are highly variable because of the effects of the MPB. This leads to some volatility in the local economy. In the medium term, the lower rate of climate change means that climate-related increases in forest productivity do not materialize. This results in smaller harvests, lower production, and fewer exports than might have been the case if climate change were more pronounced. In terms of global markets for forest products, growth in demand is flat, but anticipated increases in the global timber supply due to climate change do not materialize. As a result, real (i.e., inflation-adjusted) prices for forest products remain flat. The forest industry remains important, but production and exports are less than 50% of 2000 levels, mainly because of a combination of reduced timber supply (due to MPB, productivity effects, and wildfire) and flat prices.

Other Impacts

The impacts of climate change on agriculture, tourism, fisheries, water resources, and outdoor recreation opportunities are relatively minor. Agriculture productivity benefits somewhat from climate change in this scenario. Changes in the risk of extreme weather events are small. Thus, climate change is not a significant source of vulnerability in terms of environmental impacts on the landscape surrounding Vanderhoof.

Community Impact Scenario IV

Socioeconomic Outlook

Community impact scenario IV describes a future in which the extent of climate change is moderately high (the A2 emissions scenario), and global markets are not only weak but also unfavorable to the Vanderhoof economy. Because of the socioeconomic component of this scenario, the Vanderhoof economy would be under some pressure even without changes in the climate. The significant climate change reinforces and magnifies the economic and social challenges faced by the community by contributing to an increased global supply of agriculture and forest products at a time when global demand is relatively weak. Under this scenario, investment and technological advancement in other regions of the world are outpacing those in Vanderhoof, and, despite the community's market focus, profitability and economic diversity are low. Investment and technology remain focused on commodity markets, but unfavorable global market conditions are depressing the local economy, creating unemployment and low investment. Pressure grows for the community to deal with immediate concerns relating to issues other than climate change. The community's resources are fully engaged in dealing with these issues, and its ability to adapt to new and unanticipated challenges, including those caused by climate change, may be low.

Climate Outlook

The change in climate in the Vanderhoof area over the next 100 years is significant. Average daily temperature increases by about 2.5 °C by the year 2050 and by about 4.5 °C by 2100. Average annual precipitation increases from about 550 mm (in 2000) to about 600 mm by 2050 and 650 mm by 2100.

Forest Ecosystem Impacts

The CSIRO Mk2–A2 climate and emissions projection was used for the ecosystem analysis for this scenario. The forest in the Vanderhoof study area starts showing evidence of a shift from conifer domination to a far higher deciduous component. Conifer productivity increases, but hardwoods account for a larger portion of the forest inventory. Forest productivity increases by 30% for this scenario. (Note that the 30% value is assumed, not derived. The CSIRO Mk2–A2 scenario actually projects a 34% increase in productivity by 2050, but the value of the productivity increase has been scaled down for the purposes of this community impact scenario to reflect the assumption of lower forest sensitivity.)

Wildfire Susceptibility

The CSIRO Mk2–A2 climate and emissions projection was used for the fire analysis for this scenario. This climate and emissions projection causes the greatest temperature increases and the highest increase in precipitation of all of the projections. There is a 31%–111% increase in the proportion of critical fire weather days during the fire season. The percentage of the area in the high and extreme fire weather classes increases to some extent, but not as much as in community impact scenario III. The length of the fire season increases, and the average number of escaped fires (i.e., > 20 ha) increases from three to five per year.

Forestry-Related Impacts

The worst-case beetle scenario occurs, and harvests in the Vanderhoof study area reach the maximum fall-down around 2020. After 2020, however, harvesting opportunities increase (because of climate-induced increases in the productivity of the remaining forest). Local increases in harvest opportunity are offset to some degree by higher costs of delivered wood, because of reduced opportunitiy for winter harvest. There is also a significant increase in the timber supply in global forestry markets from other countries, and global demand for forest products is flat. Thus, Canadian producers face declines in real (i.e., inflation-adjusted) prices. The local forest industry becomes a marginal supplier and is the first to shut down during cyclical economic downturns. A persistent period of low prices (and higher costs for delivered wood) leads to some mill closures. Under this community impact scenario, climate change combined with flat markets and high costs represents a source of vulnerability to local producers of forest products. Forest industry output and exports are less than 50% of 2000 levels, mainly as a result of market pressures.

Other Impacts

Growing conditions and length of the growing season for agricultural production improve, but these changes are offset by increases in the variability of the weather. The world agricultural economy has become regionalized (through a failure to liberalize trade), and export opportunities for Canadian producers are low. There is a reduction in forest aesthetics during periods of transition from one forest type to another, which has a major negative impact on the local tourism industry. Water temperatures increase, which reduces salmon and trout populations. Winters are shorter and milder, and summers are longer. The snowpack is reduced, spring runoff occurs earlier, and summer flow rates are reduced. There is a general reduction in old-growth forest and in the population levels of wildlife species with large home ranges and those that prefer relatively pristine forest settings (such as caribou and grizzly bear); conversely, however, ungulate populations may increase. Precipitation may increase through the more frequent occurrence of intense precipitation events, leading to the possibility of an increase in the risk of flooding. There may also be a significant increase in the frequency of other forms of extreme weather (e.g., droughts, heat waves, or severe storm activity). Increased exposure of local residents to changes in the landscape and increased risks of extreme weather are sources of vulnerability under this scenario.

IMPLICATIONS FOR CANADA'S FOREST-BASED COMMUNITIES

Impacts

Forest-based communities in Canada will face similar climate change risks, challenges, and opportunities as other communities in Canada. These include the potential for increases in the frequency and magnitude of extreme weather events, health impacts, impacts on local infrastructure, and impacts on nonforestry sectors. However, over and above these general impacts, forest-based communities will face a number of additional impacts that may occur as a result of the close linkages of these communities with surrounding forests. This study has identified and discussed these additional impacts and has developed and illustrated methods for assessment.

Canada has over 320 communities, located in every province in the country, where the forest products industry accounts for more than half of the community's economic base. The economic development of these communities has proceeded on the assumption that Canada's forests are managed sustainably and that timber supply will be available in perpetuity. The assumption of a perpetual and relatively stable supply of timber has to some extent offset the need to diversify. The experience of Vanderhoof suggests that in some cases climate change may be a precipitating factor leading to a future in which local timber supply will be more variable and may not be available at the levels required to support a community's forest industry at current levels. Thus, climate change has important implications for small, remote, and relatively undiversified forest-based communities.

Each community's experience with climate change will be different. The impacts will be specific to geographic location, and appropriate adaptations will also need to reflect location. The assessment of a particular community's vulnerability will require a local analysis that takes account of location-specific factors contributing to the particular community's unique sensitivity to climate change and to the resulting forest changes. Nevertheless, the Vanderhoof case study points to some areas where forest-based communities may be particularly exposed, sensitive, and therefore potentially vulnerable to the impacts of climate change. For example, climate change affects disturbance regimes in forests surrounding communities and may affect several disturbance factors (e.g., fire, insects, drought, windstorms) at the same time. Moreover, these disturbance factors are interrelated. For example, 20th-century climate change contributed to the unprecedented MPB outbreak in Vanderhoof and the surrounding area. The resulting tree mortality is having immediate implications for susceptibility to wildfires. Once the dead needles drop, fire susceptibility is expected to decrease. However, if climate change results in warmer and drier conditions in the future, wildfire activity is projected to once again increase. Thus, local disturbance-related impacts are interrelated, complex, and dynamic.

An important disturbance-related impact of climate change will be the potential for increases in wildfire risk in communities located close to flammable forests. Increases in the frequency and intensity of wildfire in fire-prone areas will result in increased risks to property and infrastructure, increases in the need for evacuation, potential health impacts from smoke, and increases in the frequency of forest closures.

Climate change will affect resource supply in areas surrounding forest-based communities. Here again, the changes will result from multiple complex and interacting factors. Changes in disturbances may ultimately reduce resource stocks and AACs in some locations. These impacts may be dramatic and immediate. Climate change may also result in increased productivity in areas without moisture limitations, through longer growing seasons and CO_2 fertilization effects. However, the ability to exploit improved growing conditions may require forest managers to switch to different genotypes (or possibly new species) better suited to the future growing conditions. In areas with moisture limitation, climate change may result in reduced productivity and increased tree mortality. Over the long term, climate change may result in changes in the tree species composition of a particular area.

Climate change will result in higher costs for delivered wood. The most cost-effective season for harvesting is winter, when the ground is frozen. However, climate change is resulting in warmer and shorter winters, and winter harvest opportunities are decreasing (and will probably continue to decrease in the future). As a result, more all-weather roads will be needed, and delivered-wood costs will be generally higher.

Climate change may lead to increased instability in local resource supply and economic activity. For example, Vanderhoof is currently experiencing an economic boom as a result of timber supply uplifts imposed to permit the salvage of beetle-killed timber. However, within 10 years, the local supply is expected to be considerably lower than it was before the beetle event. Thereafter, timber supply is expected to increase because of a longer growing season and other factors. Thus, the responses to climate change can be both positive and negative and may be nonlinear over time.

Climate change may affect forest-based communities through structural changes in global markets for forest products. Economists have projected that the global timber supply will increase and that traditional forest industry exporters such as Canada will be negatively affected, because much of the economic benefits to producers will occur in countries that can produce timber from fast-growing plantations. Economic diversification and strategic investments by governments and firms promoting the production of nontraditional products and encouraging the development of new market niches may reduce the vulnerability of Canadian forest-based communities to changes in traditional global commodity-based markets for forest products.

Finally, climate change may result in completely unexpected changes in forest health, forest productivity, forest disturbances (such as fire), and local economic operating conditions. Climate change thus leads to an increase in uncertainty for firms, households, and governments in forest-based communities.

The sustainability of communities depends on the endowments of resources and assets to which they have access or that contribute to a community's function and purpose. These endowments are generally referred to as human capital, natural capital, infrastructure, financial capital, science and technology capital, and so on. A community's access to assets and its ability to autonomously combine assets and endowments for the benefit of the community is affected by institutions and local leadership. A significant decline in one critical asset of a forest-based community (such as the surrounding timber inventory) will have important implications if it is not replaced or substituted by alternative types of assets. The experience of Vanderhoof suggests that climate change has the potential to significantly decrease natural capital near a community. Reduction of the overall asset base supporting a community will ultimately result in local impacts and declines.

Adaptation

The kinds of impacts noted above point to a number of early actions and strategies that forest-based communities might consider, depending on factors such as the magnitude and timing of projected local impacts, the costs and benefits of adapting versus not adapting, and the degree of confidence in information about potential future impacts. To plan and prepare for climate change it is necessary to understand where the community is most vulnerable. An important first step is to assess vulnerability (see Williamson et al. 2007). Given the chronic, cumulative, and incremental nature of climate change, it will be important for communities to then begin to monitor, evaluate, and continuously assess local change. Climate change will probably increase the frequency and intensity of extreme weather and climate events, which suggests a need to determine whether local emergency preparedness measures are adequate. Climate change may increase fire frequency and intensity in some regions, and communities and individual property owners may want to consider options for reducing the risk of fire (e.g., Fire Smart properties, communities, and landscapes). Climate change will affect land use and resource management, and communities will therefore want to participate in decision-making in these areas. Communities may find it useful to incorporate climate change considerations into their economic development planning by considering the types of human-made capital (e.g., buildings, manufacturing equipment, and infrastructure) and natural capital (e.g., forests and water resources) currently supporting the local economy, the extent to which these assets will be affected by global changes (in both the market and the climate) and whether the community can reduce its exposure and risk by advocating change in land use and forest management practices, replacing or substituting vulnerable assets with less vulnerable assets, or diversifying the economy. Finally, given the increased potential for surprises and the ongoing changes that are expected, communities should, where possible, adopt policies to maintain and strengthen their adaptive capacity, which is determined by an array of characteristics, including financial resources, diversification, strong social capital, strong local leadership, high levels of human capital, flexibility, local autonomy to adapt, access to science and information, and the presence of an informed and proactive population.

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APPENDIX 1

DESCRIPTIONS OF ECOREGIONS CONTAINED WITHIN THE STUDY AREA

Descriptions of ecoregions contained within the study area

	Fraser Plateau	Fraser Basin
Climate		
Mean annual temperature (°C)	3	3
Summer mean temperature (°C)	12.5	12.5
Winter mean temperature (°C)	7	8
Mean annual precipitation (mm)	250–600	600–800
Vegetation	■ Dominated by white spruce, lodgepole pine, trembling aspen, and Douglas-fir forests ■ Open-growing lodgepole pine and Douglas-fir occur on drier mid-elevation sites ■ Engelmann spruce and alpine fir are found at subalpine elevations, usually above 1250 m above sea level ■ Bunchgrass-dominated grasslands occur at valley-bottom elevations along the Fraser and Chilcotin rivers ■ Localized alpine tundra vegetation occurs on the summits of the Quanchus Range south of Ootsa Lake and the shield volcanoes of the Ilgachuz and Itcha ranges	■ Mixed stands of trembling aspen, paper birch, lodgepole pine, and the climax species, white and black spruce ■ The subalpine zone that occurs above 1200 m above sea level supports forests of lodgepole pine, which develop after fires, as well as Engelmann spruce and alpine fir
Topography	■ Broad, rolling plateau generally 1150–1800 m above sea level ■ Well-developed drumlinoid features, pitted terraces, simple and compound eskers, and areas of glacial lake (lacustrine) deposits	■ Underlain by flat-lying Tertiary and volcanic bedrock that generally lies below 1000 m above sea level ■ Gently rolling surface covered by thick glacial drift into which the Fraser River and its major tributaries are commonly incised ■ Glacial deposits include moraine with well-developed drumlinoid features, glaciofluvial terraces, eskers, and large areas of glacial lake deposits

Adapted from Ecological Stratification Working Group. 1995. A national ecological framework for Canada. Agric. Agri-Food Can. and Environ. Can., Ottawa, ON.

APPENDIX 2

METHODOLOGY FOR ANALYSIS OF CLIMATE CHANGE AND WILDFIRE SUSCEPTIBILITY

This appendix describes the BURN-P3 model inputs and model assumptions for the wildfire susceptibility analysis of the Vanderhoof study area.

Fire Frequency

Fire activity simulated by BURN-P3 is intended to reflect fire processes known to operate in the area under investigation. Historical fire activity in the study area was assessed both to calibrate BURN-P3 settings and to define key model inputs. Historical fire records obtained from the British Columbia Ministry of Forest and Range contain point fire locations for all fires that occurred in the study area between 1950 and 2002. Historical fire polygons are also available, providing a relatively complete record of fires ≥ 20 ha. For example, for the period 1970–1999, polygon records are available for 98 of the 132 fires with a final size ≥ 20 ha that occurred in the study area. Although the number of missing polygon records is significant, the missing fires were all relatively small. As a result, the polygons represent 79% of the area burned by all recorded fires in the study area over the period 1970–1999. Point and polygon records were used to investigate changes in fire activity over the period 1920–2002.

Polygon records of areas burned by large fires (≥ 20 ha) in the study area between 1920 and 2002 (Figure A2.1) indicate that more than 97% of the area burned over this time period was burned in fires that occurred before 1970. Records of fire activity before 1950 are limited to the provincial fire polygon database, which is in turn limited to fires ≥ 20 ha and which generally lacks detail relative to the point fire database used to describe later time periods. Between 1920 and 1949, fires burned an average of 23 570 ha each year or 0.63% of the 4 million ha study area, minus the portion of that area covered by water (243 430 ha). With an annual percent burned of 0.63, it would take 159 years to burn an area equivalent to the Vanderhoof study area. Almost all (87%) of the area burned reported during this time period was attributed to fires caused by people, most likely associated with land-clearing activities.

Detailed records of point fire locations between 1950 and 1969 indicate that an average of 80 fires occurred each year, burning an average of 4 330 ha annually. On average, fires burned 0.12% of the study area each year, which means it would take 868 years to burn an area equivalent to the Vanderhoof study area. Fire activity declined markedly after 1970. Between 1970 and 2002, the number of fires in a given year ranged from 12 to 262 (average 96), and area burned ranged from 16 to 4 345 ha. On average, fires burned only 0.02% of the study area each year, which means it would take over 4 000 years to burn an area equivalent to the Vanderhoof study area.

Given the changes in fire activity over the period 1920–2002 (Figure A2.1, Table A2.1), BURN-P3 inputs and model calibration were based on fire activity limited to the baseline period 1970–2002. By restricting the analysis of model inputs to this 33-year period, it is possible to ensure that BURN-P3 will simulate fire processes that can reasonably be expected to remain constant in the near to short term (i.e., within 1–4 years). Fire activity fluctuated from year to year during the period 1970–2002, but overall, fire sizes and area burned were relatively stable throughout this time.

Fire Season

Forest fires in the study area occur primarily between the months of April and October (Figure A2.2). Fires caused by people peak in early May and then decline to relatively stable levels from June to September. Lightning-caused fires begin to increase in early July, peak in early August, and decline sharply to low levels by mid-September. On the basis of these seasonal patterns, the fire season was defined as the period between 1 May and 30 September. Spring and summer seasons were defined to reflect both the end of the peak in people-caused fires and the onset of increased lightning-caused fire activity.

The division between spring and summer was also defined to reflect seasonal patterns in fire weather. Weather records for the period 1984–2004 were examined to investigate the likelihood that a given day in the fire season

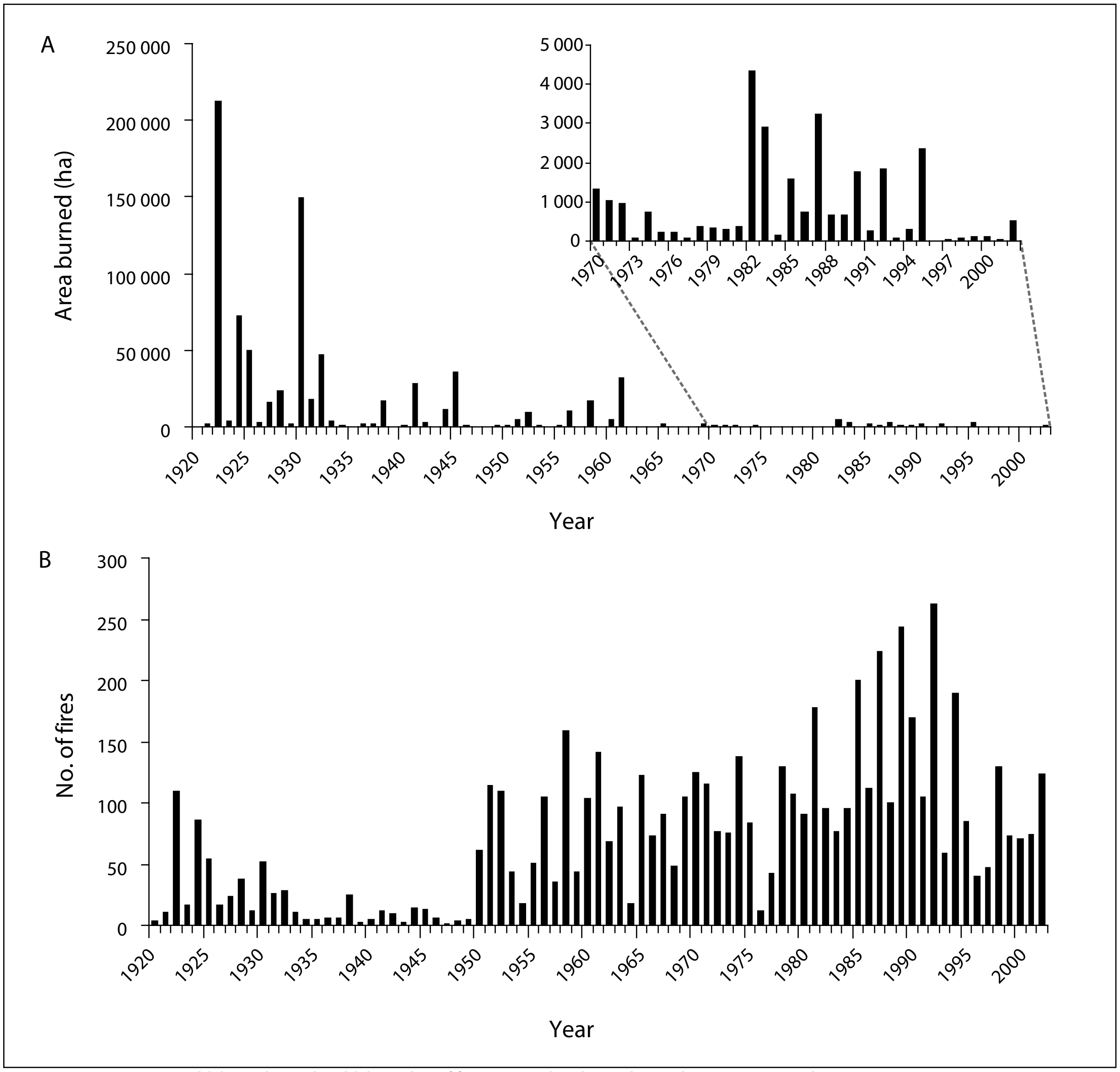

Figure A2.1. Annual (A) area burned and (B) number of fires reported in the study area between 1920 and 2002.

Table A2.1. Fire activity summary for three time periods

Fire activity	1920–1949	1950–1969	1970–2002
Average annual % burned	0.63	0.12	0.02
Fire cycle (years)	159	868	4 478
% of area burned attributed to lightning	13	40	27
% of fires caused by lightning	7	24	36
Average annual area burned by lightning fires (ha)	3 180	1 710	226

would be associated with fire weather conducive to extreme fire behavior. For each day in the fire season, the percent of times that that day was associated with British Columbia fire danger class 4 or 5[1] was calculated (Figure A2.3). The results indicated a division in fire weather occurring in early July, characterized by dramatic increases roughly consistent with the onset of lightning-caused fire activity. As a result, 7 July was chosen as the dividing point between spring and summer seasons as modeled in BURN-P3.

Escaped Fires

BURN-P3 is a coarse-scale model and is limited to simulating the main impacts associated with fire processes on a given landscape. For this reason, only the growth of large fires is simulated during each model iteration; no attempt is made to represent the contribution of small fires to the likelihood that a given landscape pixel will be burned. The size limits used to define small and large fires are determined from historical fire records specific to the landscape under investigation. In some areas, large fires may routinely exceed 200 ha, whereas in other areas, fires of 10–20 ha may be considered "large" relative to the population of fire events in the historical record.

Historical fire sizes in the Vanderhoof study area suggest that a fire exceeding 20 ha should be considered a relatively large fire (i.e., an "escaped fire"). Two important BURN-P3 inputs are the annual number of escaped fires and the percentage of escaped fires that are associated with a given cause and season. Between 1970 and 2002, a total of 99 fires >20 ha occurred in the study area during the fire season, an average of three "escaped" fires per year. Most escaped fires (89%) were caused by people. Fire escape rates for BURN-P3 by cause and season are shown in Table A2.2.

Fire Size

Fire growth simulations in BURN-P3 are carried out with the Prometheus fire growth model. To begin a simulation, Prometheus requires information about the location of the fire ignition, the weather conditions under which the fire will grow, and details about the duration of fire growth simulations, in terms of the number of hours per day that each fire will grow and the total number of days of active fire growth. Weather conditions and inputs related to the duration of fire growth must be suitable for modeling fires that achieve the minimum size used to define "escaped fires," in this case greater than 20 ha. Suitable weather conditions can be determined from historical data, described in the section below entitled "Fire Weather Conditions." The duration of fire growth is determined from a calibration process, to ensure that the fires produced by BURN-P3 are realistic, given the actual fire-size distribution that is characteristic of the study area.

Between 1970 and 2002, forest fires in the study area ranged in size from 0.1 ha to 2 741 ha. Most fires (79%) were less than 1 ha, and only 5% exceeded 10 ha (Figure A2.4). Forest fires can achieve their final size over the course of one or more days. It is not uncommon for large fires to burn over several weeks, during which a small number of days with active fire growth are intermixed with a larger number of days with little to no growth. Representative estimates of fire sizes can be obtained by simulating fire growth during the relatively small number of days on which fires achieve most of their spread. In BURN-P3, these days are referred to as "spread-event days" and are input into the model as a distribution, so the number of spread-event days associated with a fire growth simulation will vary.

Table A2.2. Percentage of escaped fires,[a] by season and cause, based on historical fire activity between 1 May and 30 September over the period 1970–2002

	Cause	
Season	Human	Lightning
Spring	53	9
Summer	36	2

[a]Fires that attained final size > 20 ha.

[1]Schedule 2: Fire danger class. Section 6 of Wildfire Regulation B.C. Reg. 38/2005. Consolidated to July 13, 2006. Last amendment: B.C. Reg. 215/2006. Accessed 22 January 2008. http://www.for.gov.bc.ca/tasb/legsregs/WILDFIRE/wildfirereg/wildfirereg.htm#sch2.

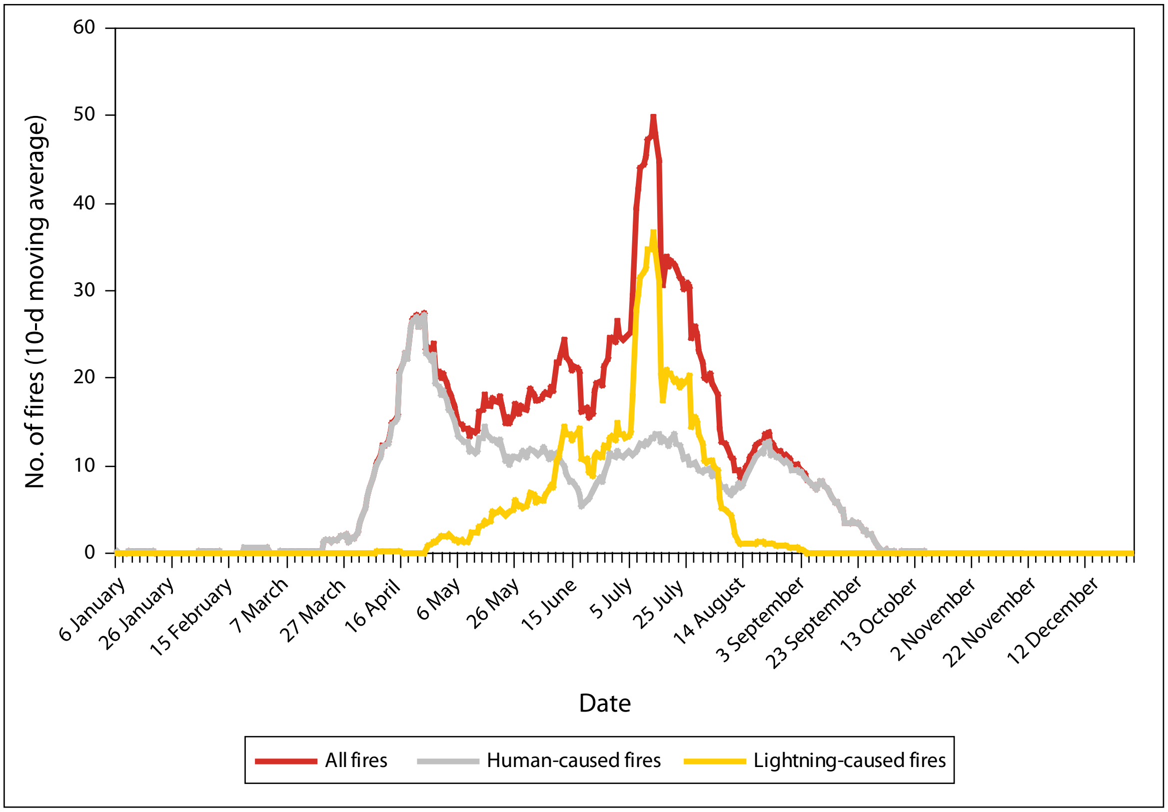

Figure A2.2. Number of fires recorded on a given date in the fire season over the period 1970–2002, by cause. Values are 10-day moving averages of the sum of fires (1970–2002) that occurred on each date.

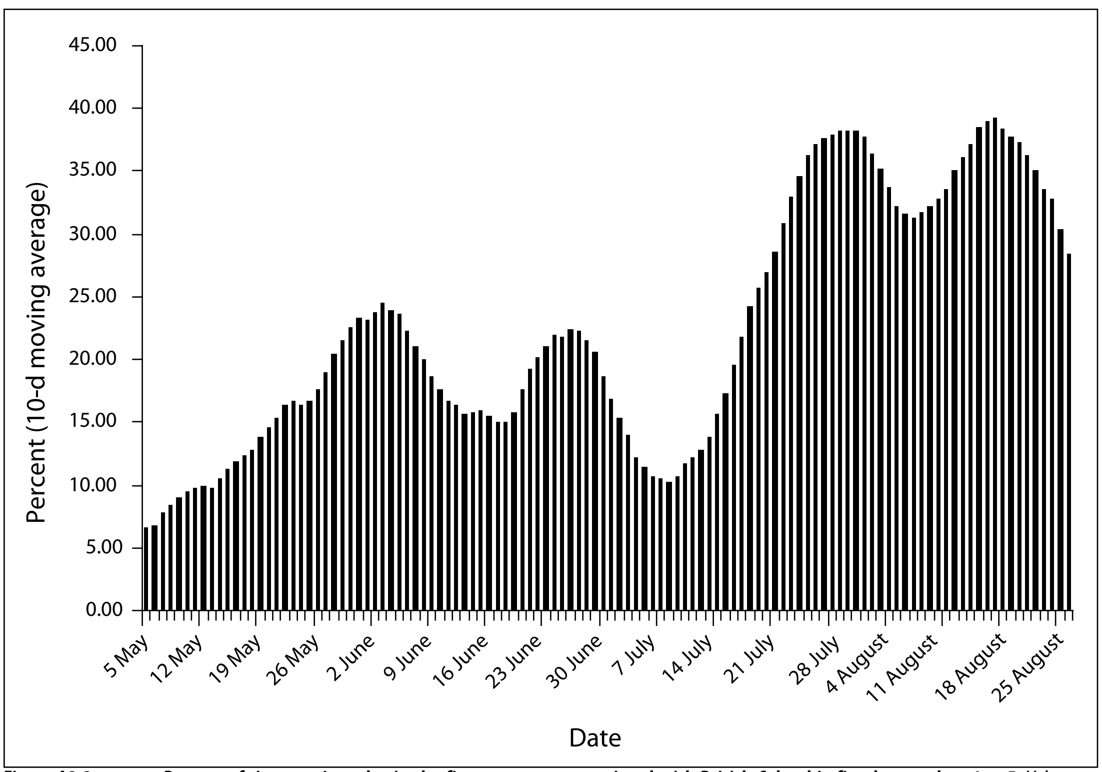

Figure A2.3. Percent of times a given day in the fire season was associated with British Columbia fire danger class 4 or 5. Values are 10-day moving averages of the percent of times danger class 4 or 5 occurred on a given day over the period 1970–2002.

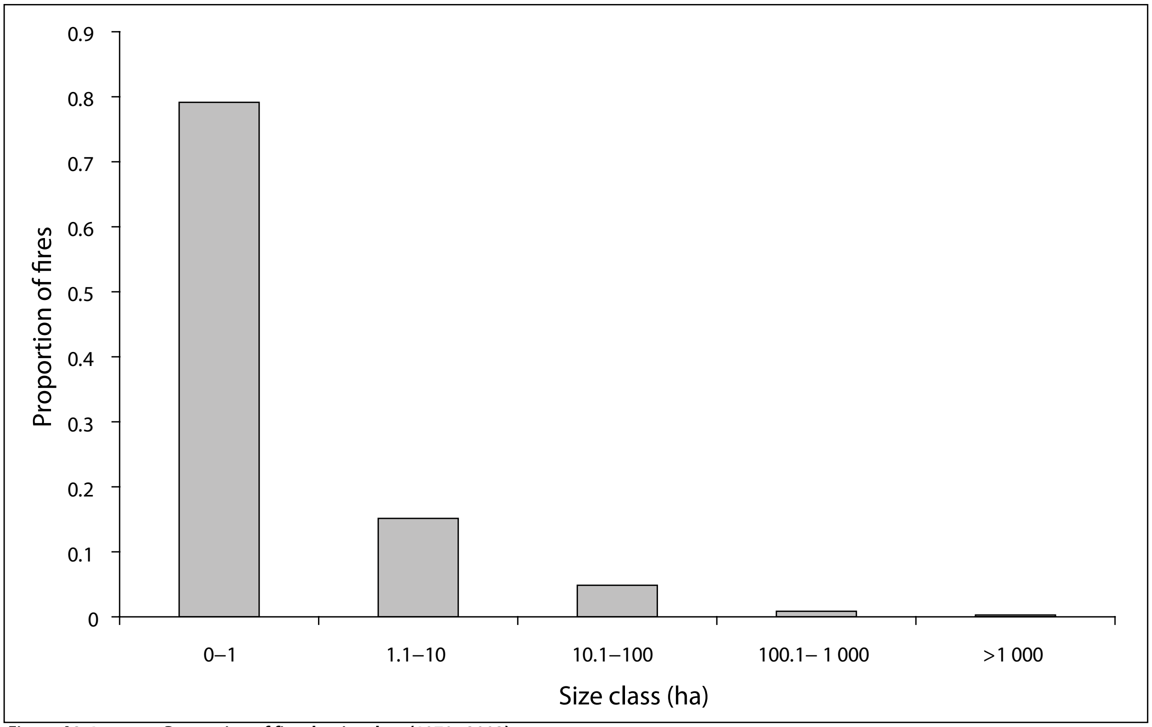

Figure A2.4. **Proportion of fires by size class (1970–2002).**

The duration of fire growth for each simulated day must also be input into BURN-P3. Unlike the number of spread-event days, the daily hours of burning are the same for every fire and every spread-event day simulated by BURN-P3. Large forest fires can be expected to achieve significant fire growth during peak burning conditions, which occur in the late afternoon or early evening. By modeling fire growth during the 1–3 h when these peak conditions occur, BURN-P3 attempts to simulate the most significant fire behavior.

The length of the daily burning period and the spread-event day distribution were determined through a calibration process. Inputs that produced fire sizes consistent with the period 1970–2002 were chosen. The selected inputs were a daily burning period of 2 h and a spread-event distribution resulting in 75% and 25% of fires with one and two spread-event days, respectively. The fire size distribution produced with these inputs was very similar to the historical distribution (Table A2.3). BURN-P3 produced slightly more fires in the 100.1–500 ha class and slightly fewer fires in the largest size class (1000.1–5000 ha). An exact match with historical fire sizes is not expected, because factors that influence fire growth, such as landscape fuel types present, are represented in their most recent state, which may differ significantly from conditions during the early part of the baseline historical period.

Table A2.3. **Proportion of fires, by size class, between historical conditions (1970–2002) and BURN-P3 simulations**

Size class (ha)	1970–2002	BURN-P3
20–50	0.44	0.32
50.1–100	0.29	0.27
100.1–500	0.20	0.36
500.1–1 000	0.01	0.03
1 000.1–5 000	0.06	0.01

Spatial Patterns

The locations of fires represented by point (1950–2002) and polygon (1920–1999) records (Figures A2.5 and A2.6) indicate that fires have occurred throughout the study area. General spatial patterns of fire activity can be incorporated into BURN-P3 simulations through optional inputs that reflect ignition patterns

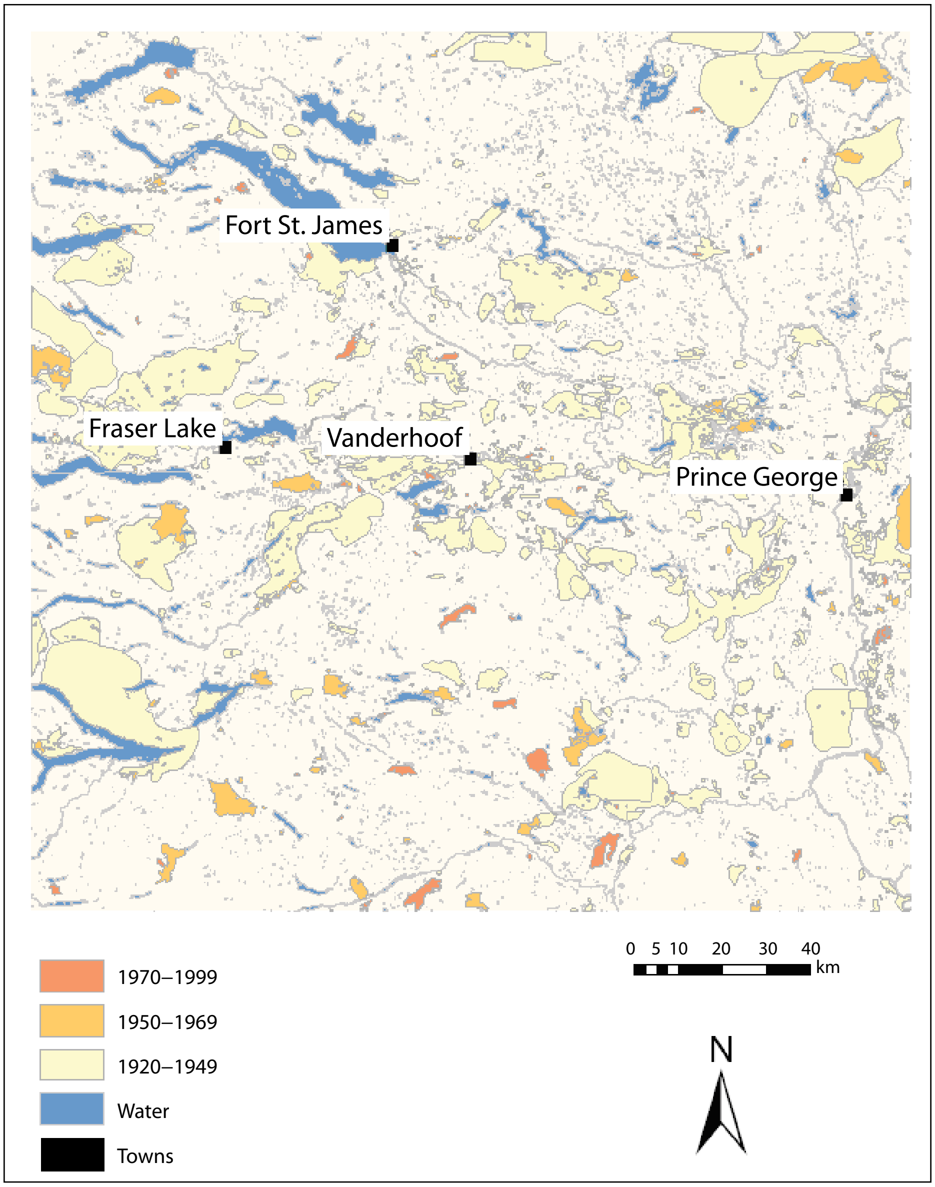

Figure A2.5. Locations of large fires (≥20 ha) that occurred within the study area during 3 time periods.

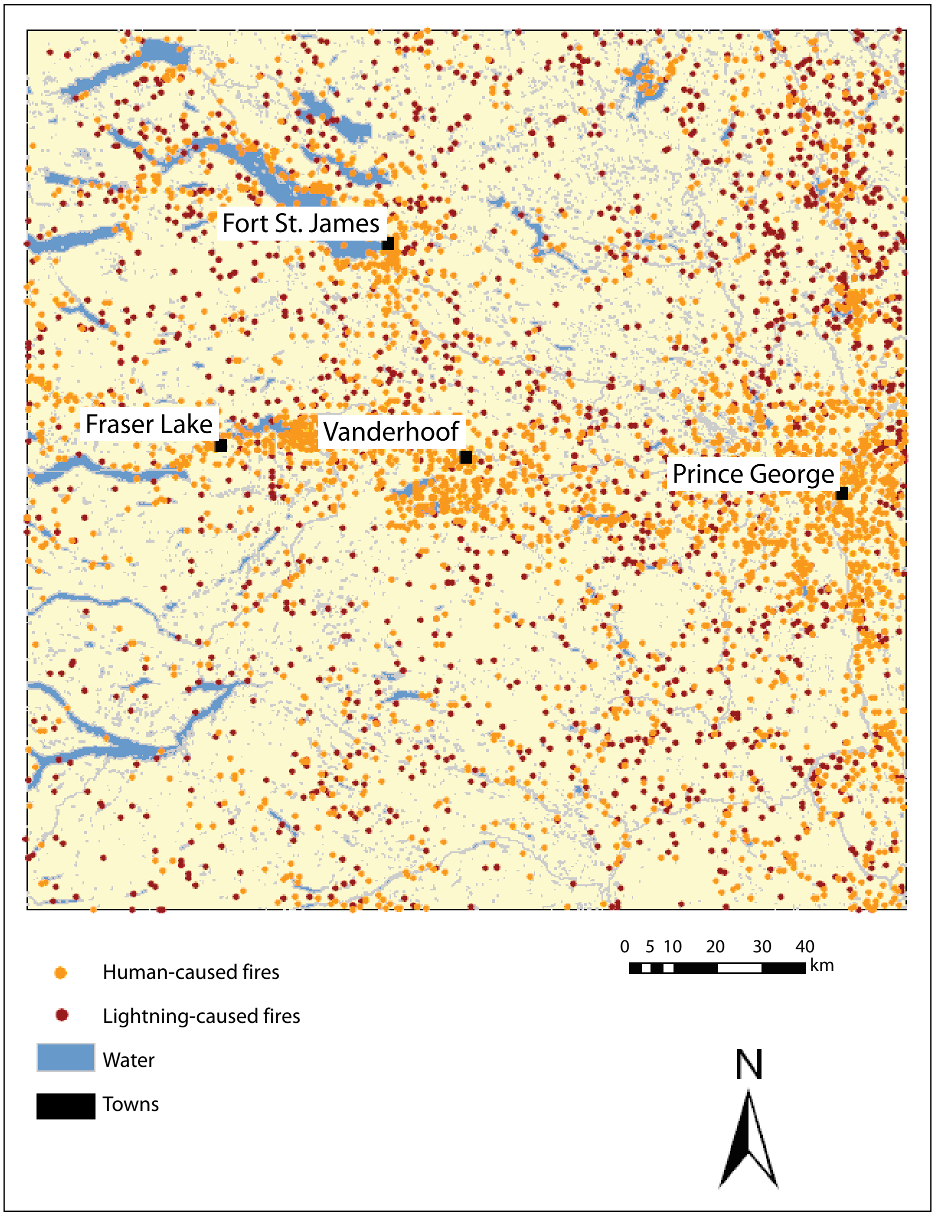

Figure A2.6. **Point locations of fires that occurred within the study area between 1950 and 2002.**

and fire regime zones. These inputs function as a coarse-scale guide for locating ignitions on the landscape during simulations. Kernel density maps were used to investigate patterns among fires caused by lightning and people. The densities of lightning-caused fires over the period 1950–2002 were relatively low across the entire study area (Figure A2.7). The patterns of lightning-caused fires were relatively consistent between the two ecological regions (Fraser Basin and Fraser Plateau), which suggested that fire processes should not be modeled separately; therefore, the entire study area was treated as a single fire zone, with the same inputs being used for BURN-P3 modeling throughout.

The densities of human-caused fires were also quite low, although concentrations were evident around communities and along transportation corridors (Figure A2.8). The proportion of area burned attributed to different causes (Figure A2.9) suggests that over the period 1970–2002, significant human-caused fires have been associated primarily with railroad and fire-use ignition sources. This differs from the earlier period 1950–1969, when the most common specified human-caused ignition source was smoking. Because the significant human-caused fire-ignition sources in recent years should be responsive to control and mitigation activities, historical patterns may not necessarily be relevant to simulations of future conditions.

Historical ignition patterns can also be expected to reflect fuel conditions, which can change significantly over time. The BURN-P3 modeling scenarios involved significant modifications of the fuel types in the study area, which makes the relevance of historical ignition patterns questionable. To avoid restricting fire-ignition processes to historical conditions for the two wildfire scenarios addressing future conditions, BURN-P3 ignitions were modeled randomly across the study area for all four scenarios. Random ignitions can be considered relatively consistent with the pattern of lightning-caused ignitions in the study area.

Fuel Conditions

The Canadian Forest Fire Behavior Prediction (FBP) System provides models for predicting fire behavior in 16 standard fuel types. Spatial coverages of vegetation data for each modeled area are used to classify landscape cover types into one of the standard FBP fuel types. Some vegetation types will not match any of the available FBP fuel types, and a surrogate fuel type must be chosen that best represents the expected fire behavior. The most recent FPB fuel-type classification of the study area was completed in 1999 (Figure A2.10), but significant portions of the study area have since been affected by the mountain pine beetle (MPB) (Figure A2.11). The baseline, pre-MPB fuel classification was used to create 2 other fuel maps for use in the BURN-P3 simulations.

The fuel map used to model the current conditions scenario (Figure A2.12) was created by modifying baseline FBP fuel types to reflect the fire behavior expected in red-stage and gray-stage lodgepole pine stands. Experts were consulted to determine the best representative fuel types (S. Harvey, senior project officer, Prince George Fire Centre, BCMOFR, Prince George, British Columbia; D. Marek, forest protection technician, Northwest Fires Centre, BCMOFR, Smithers, British Columbia; N. Lavoie, leader, Fire Sciences, BCMOFR, Fire Management Section, Victoria, British Columbia; S. Taylor, fire researcher, Pacific Forestry Centre, Victoria, British Columbia; personal communications). Gray-stage mature lodgepole pine stands were modeled as the M-2 Boreal Mixedwood fuel type with a 25% conifer component. Red-stage mature lodgepole pine stands were modeled as the C-2 Boreal Spruce fuel type.

The fuel map used to model the two future condition scenarios (Figure A2.13) was intended to represent an optimistic prediction about fuels in the study area. Specifically, it was assumed that any areas affected by the MPB would be in a relatively low-flammability state between 2041 and 2060. As a result, mature lodgepole pine stands were reclassified as M-2 Boreal Mixedwood (25% conifer) in all areas where the MPB had progressed as of 2004. Immature lodgepole pine stands were reclassified as C-4 Mature Jack or Lodgepole Pine. These changes represent an extremely simplistic effort to predict fuel conditions in the future. The optimistic assumption about fuel changes in MPB-affected areas is only one of many potential future outcomes than could reasonably be expected to occur, and many other factors, such as harvesting

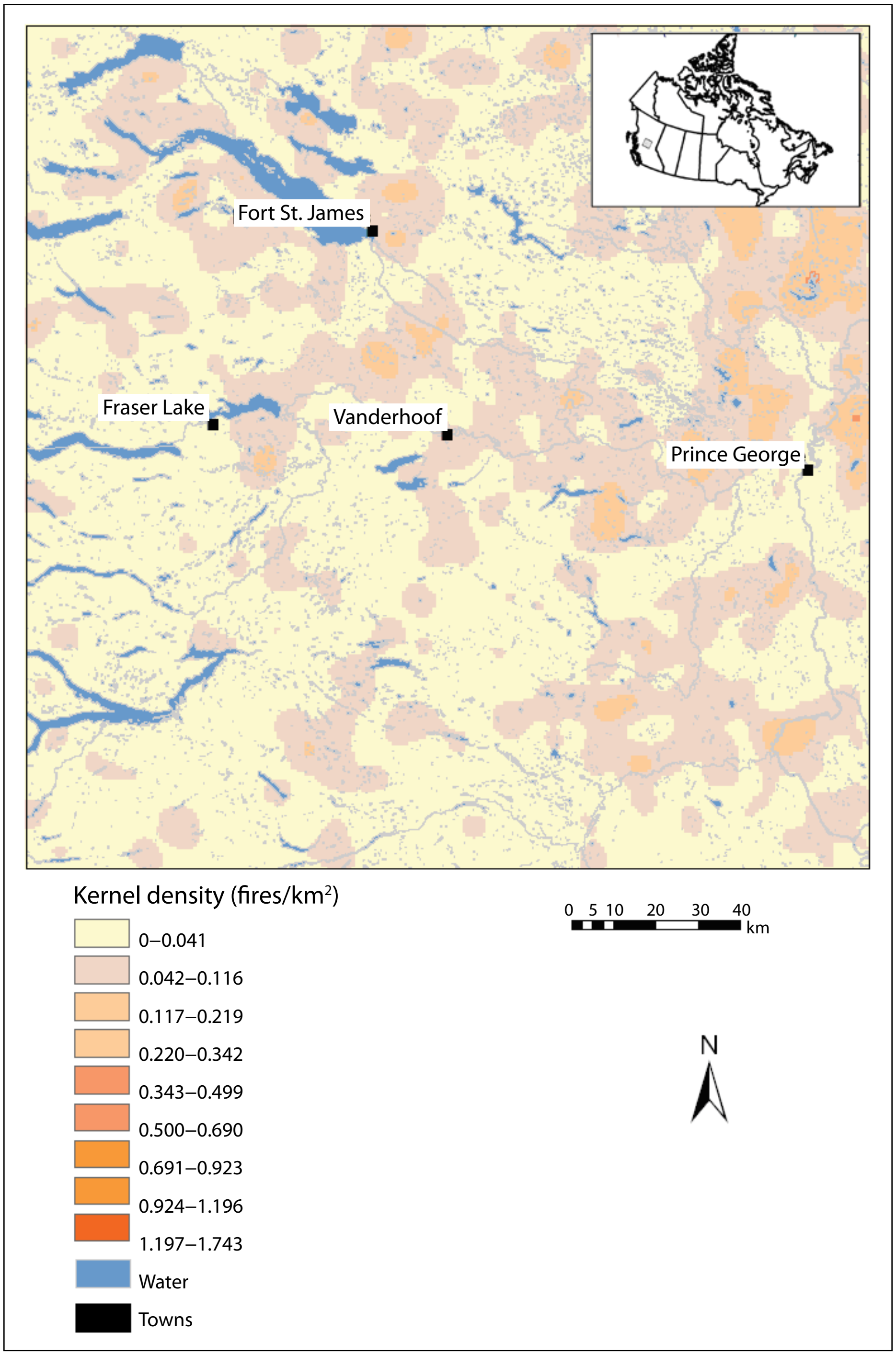

Figure A2.7. **Kernel density (fires/km^2) of lightning-caused fires that occurred within the study area between 1950 and 2002.**

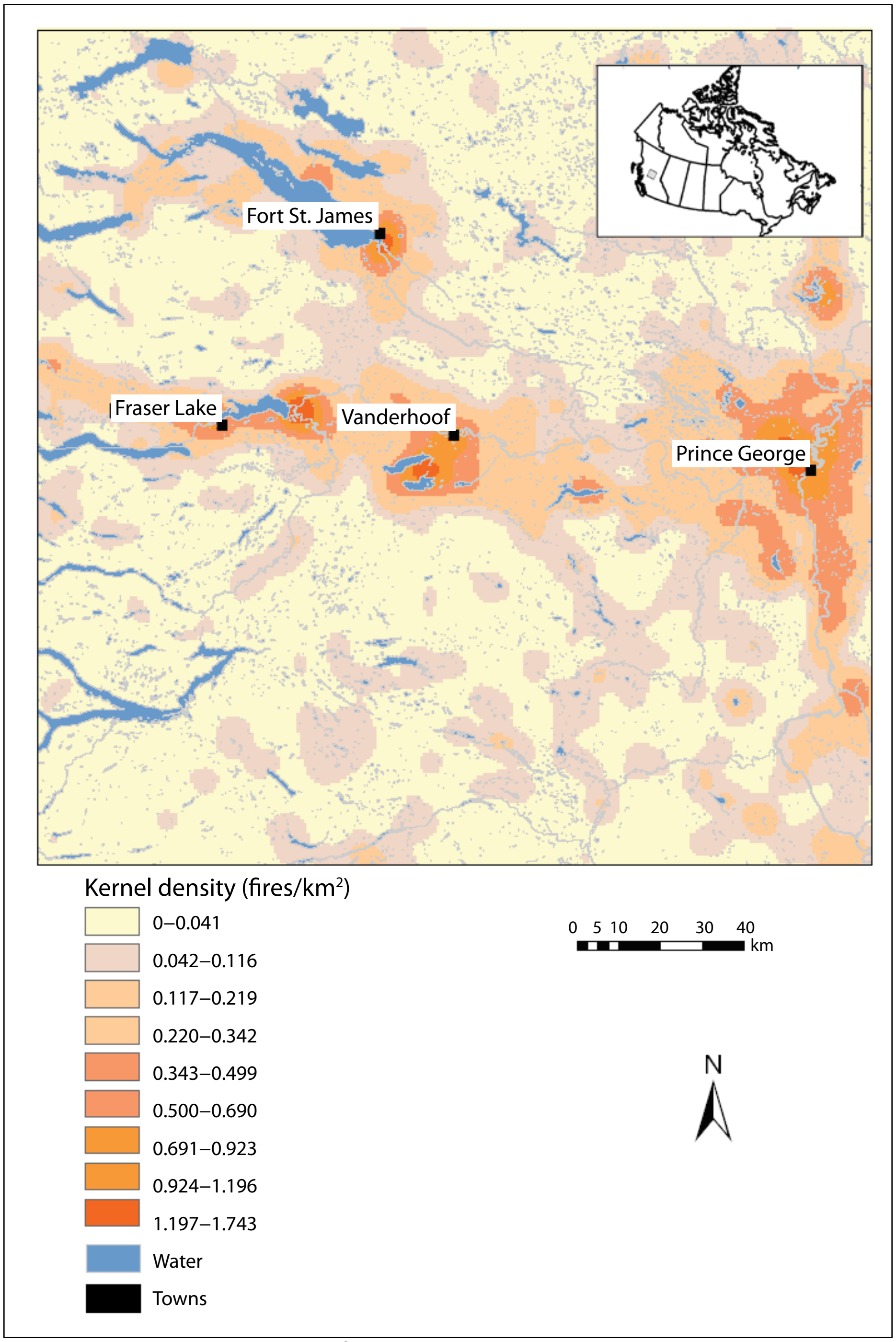

Figure A2.8. **Kernel density (fires/km^2) of human-caused fires that occurred within the study area between 1950 and 2002.**

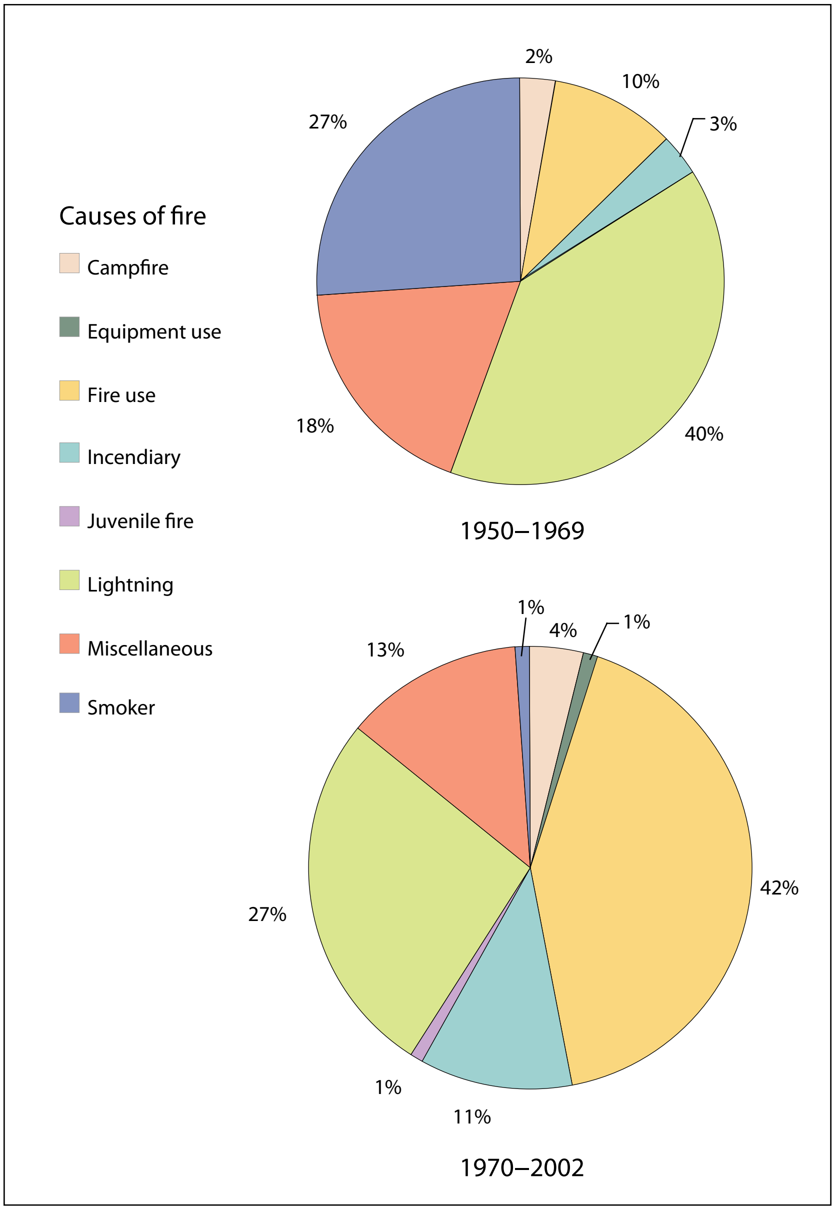

Figure A2.9. **Percent of area burned associated with various fire causes for the periods 1950–1969 and 1970–2002.** Note: causes of fire totaling <1% have not been reported in this figure.

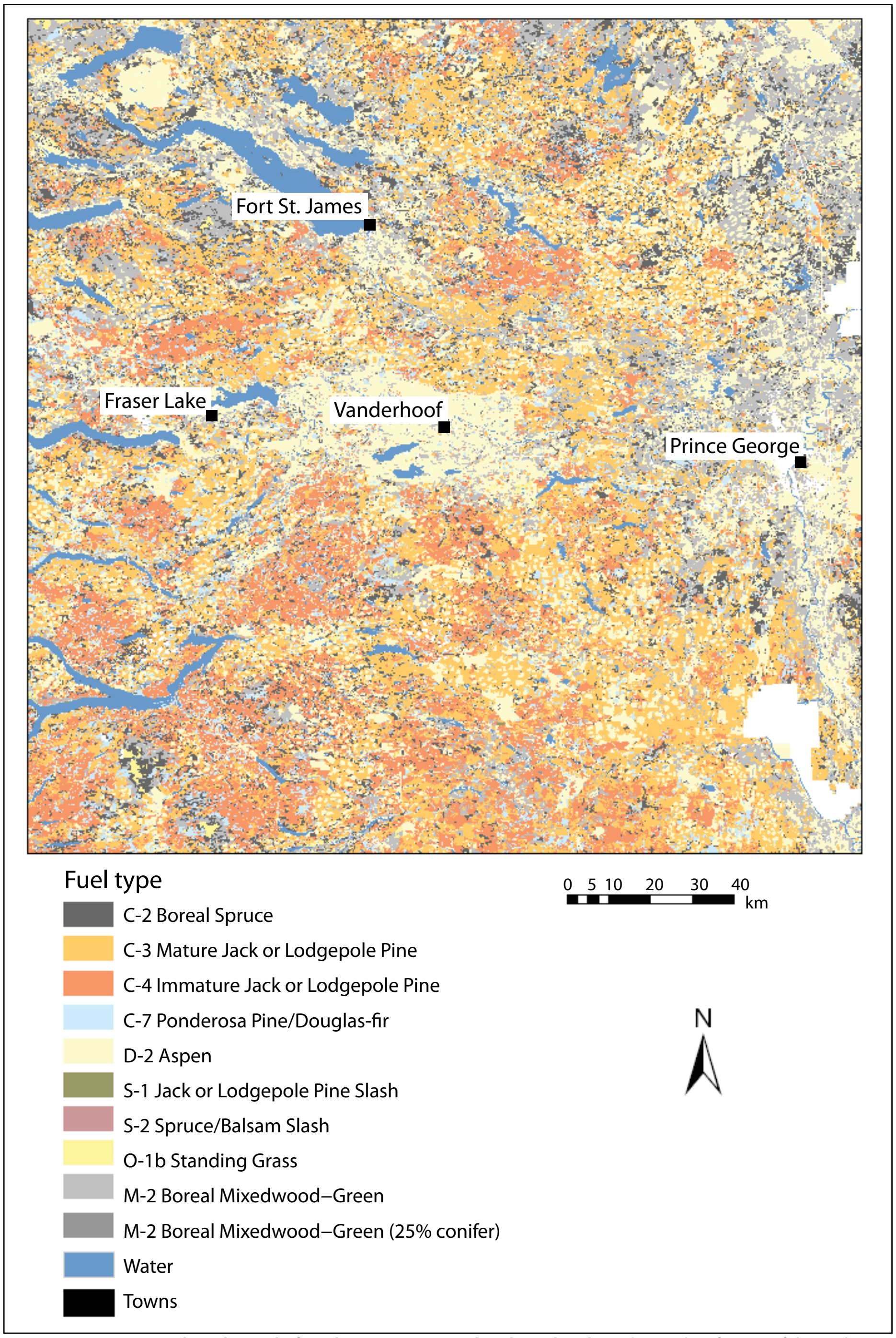

Figure A2.10. **Fuel conditions before the mountain pine beetle outbreak.** Fuel-type classification of the study area vegetation is based on the standard fuel types of the Canadian Forest Fire Behavior Prediction System.

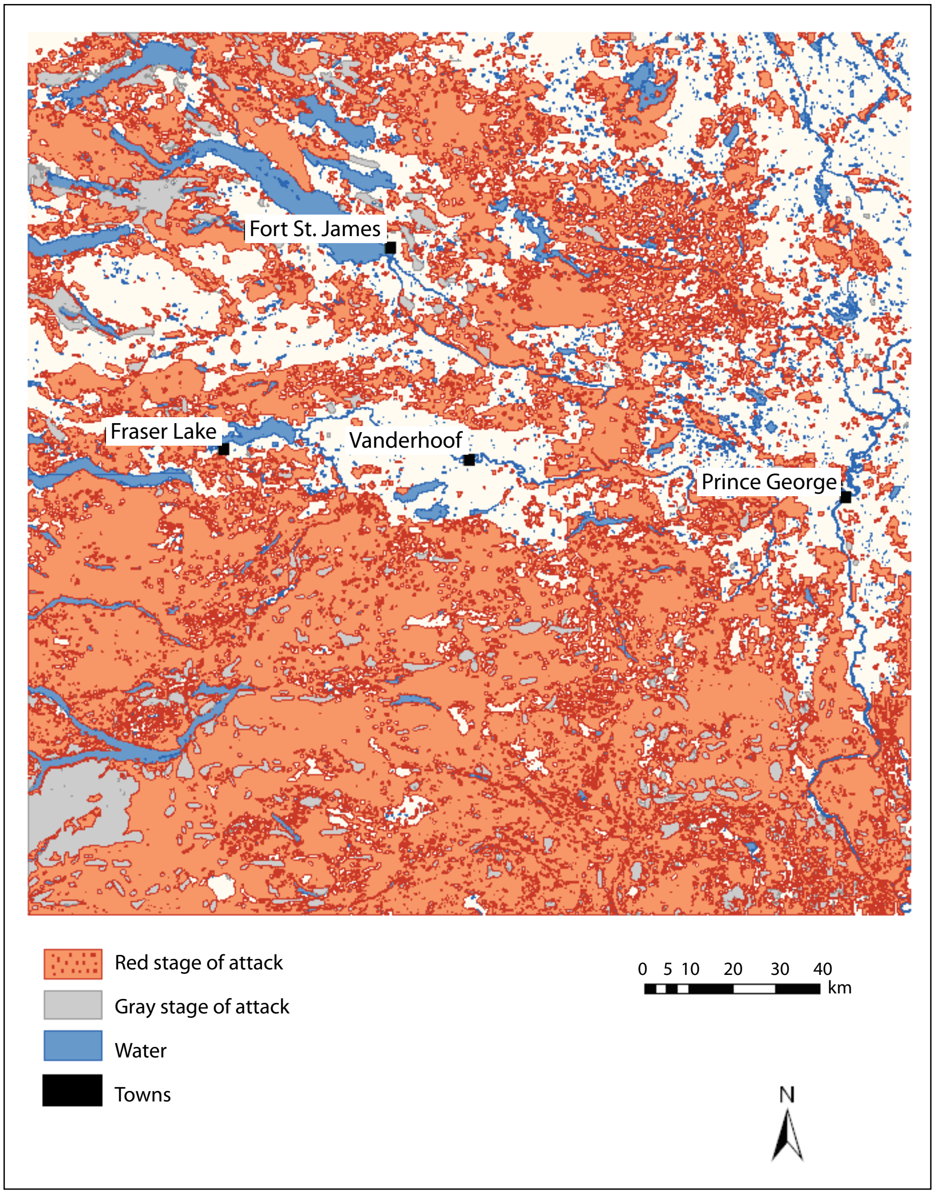

Figure A2.11. Extent of red- and gray-state mountain pine beetle attack in 2004. Red state is where trees have been recently killed and the dead (red) needles remain on the trees. Gray state refers to the time after the needles fall off the trees before significant amounts of new biomass (vegetation and thus fuel) grow in the area.

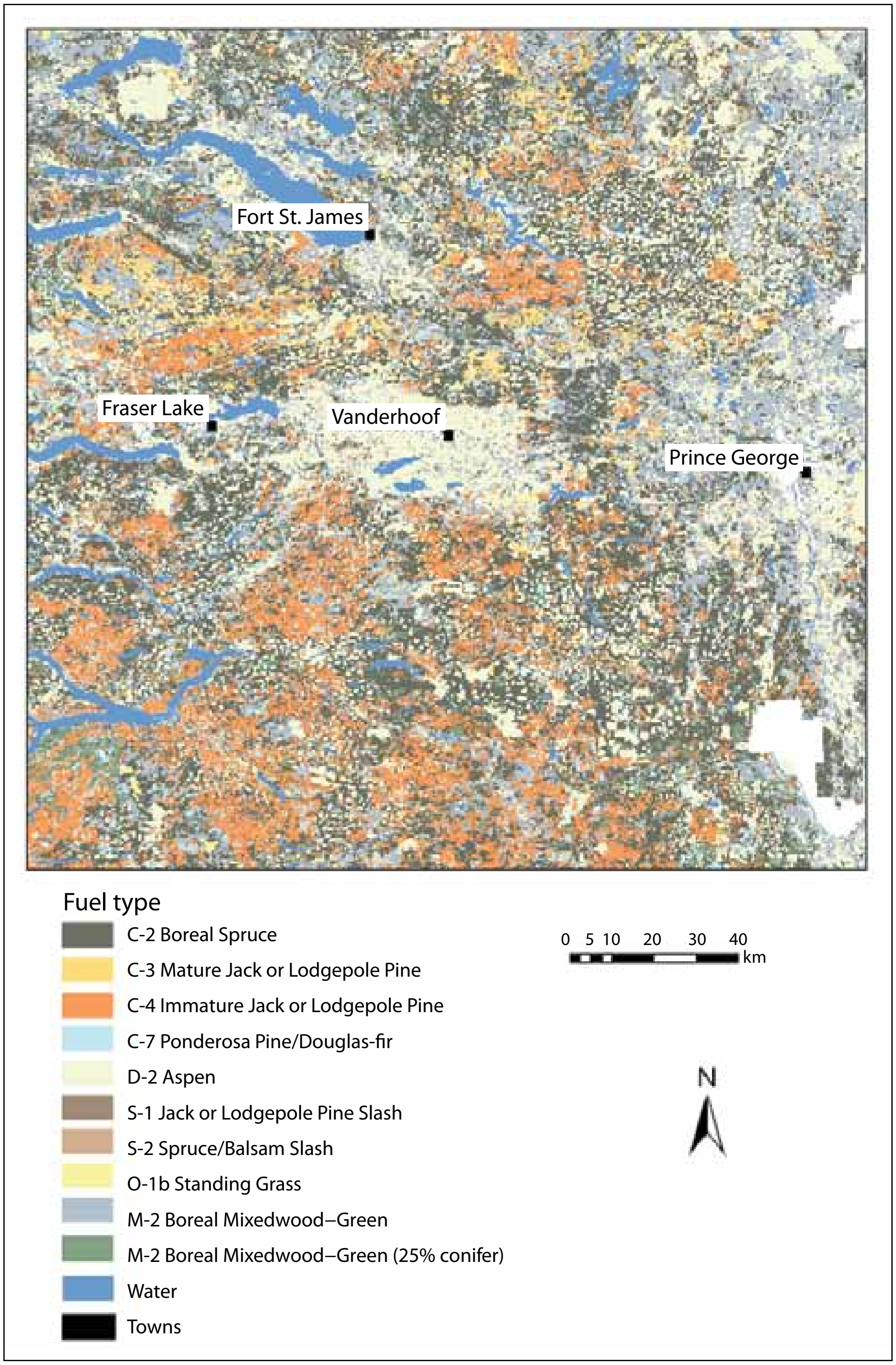

Figure A2.12. **Estimated current fuel conditions.** Fuel-type classification of the study area vegetation is based on the standard fuel types of the Canadian Forest Fire Behavior Prediction System. Mature lodgepole pine stands were reclassified as C-2 Boreal Spruce and M-2 Boreal Mixedwood (25% conifer) in areas where the mountain pine beetle had progressed to red and gray stages, respectively.

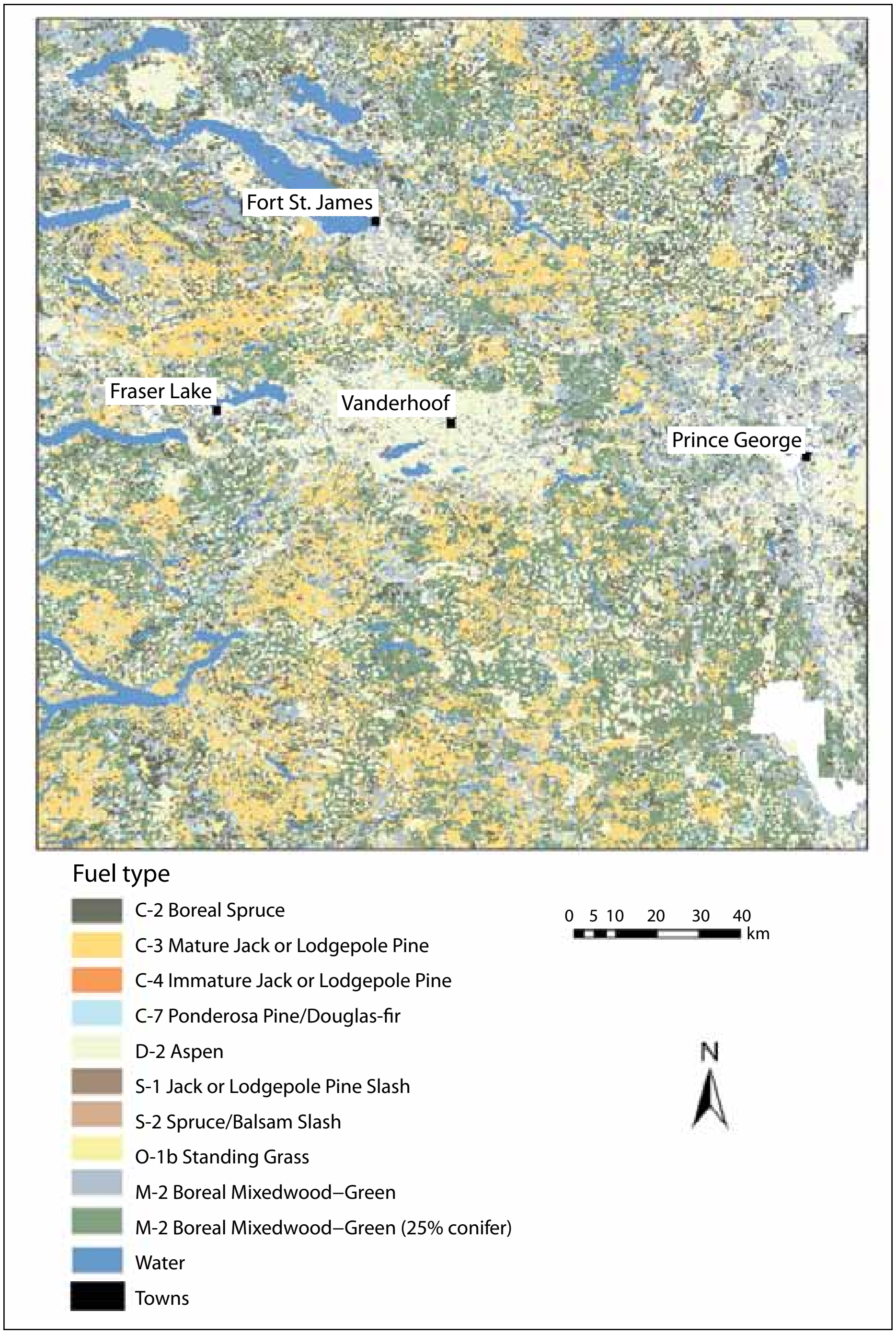

Figure A2.13. **Estimated future fuel conditions.** Fuel-type classification of the study area vegetation is based on the standard fuel types of the Canadian Forest Fire Behavior Prediction System. Mature lodgepole pine stands were reclassified as M-2 Boreal Mixedwood (25% conifer) in all areas where the mountain pine beetle had progressed. Immature lodgepole pine was reclassified as C-4 Mature Jack or Lodgepole Pine in all areas where the mountain pine beetle had progressed.

activity, future fire and insect disturbance, and natural succession, can be expected to alter future fuel conditions. The simplistic approach used for this study was intended only to provide insight into relative interactions among fire processes, fuel conditions, and fire weather in the study area.

Relative fuel-type differences associated with the three fuel maps used in the modeling scenarios are shown in Figure A2.14. MPB disturbance has "homogenized" large portions of the study area, producing vast areas that are in a recently disturbed state, which lends some support to the simplistic approach used to classify future fuels. Analysis of historical data suggests that future fires can be expected to reflect fuel conditions created by historical disturbances. For example, 41% of the study areas burned by fires before 1950 (Figure A2.15) now contain lodgepole pine in mature (18%) and immature (23%) states. Similarly, a significant proportion (24%) of the land covered by immature lodgepole pine is located in areas that were burned by fires before 1950. Another dominant fuel type in burned areas is aspen, which covers 29% of areas burned before 1950 and 61% of areas burned after 1950 (Figure A2.16). Only 18% of the area burned after 1950 contains lodgepole pine.

Fire Weather Conditions

Baseline Weather

Fire weather records for 37 weather stations located within the study area were obtained from the British Columbia Ministry of Forest and Range. Each station was evaluated according to completeness for the 153-day fire season (1 May to 30 September) over the baseline historical period defined for BURN-P3 modeling (1984–2004). The duration of weather record coverage differed among stations, ranging from less than 1 complete fire season to 35 fire seasons. Six stations had relatively complete weather records for the fire season throughout the baseline time period. Wherever possible, records from weather stations near the primary stations were used as substitutes for days with missing data (Figure A2.17, Table A2.4). A small number of missing records for the early spring season could not be substituted from a nearby station (Table A2.5).

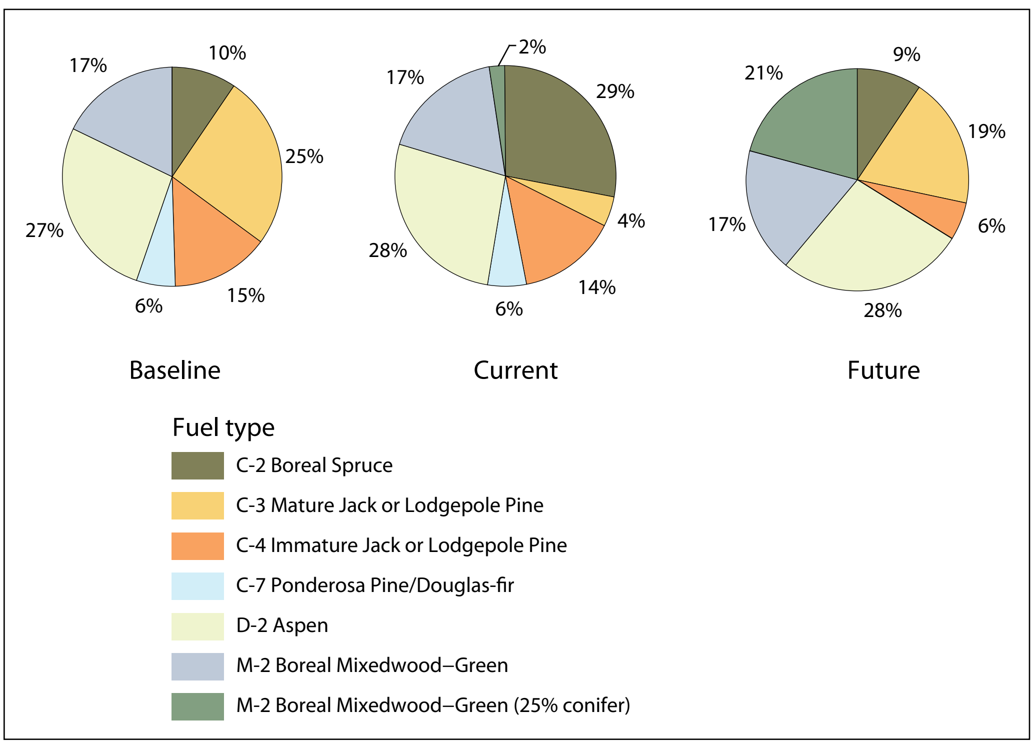

Figure A2.14. Proportional area for fuel types associated with the three fuel maps representing baseline (before mountain pine beetle outbreak), current, and estimated future conditions. Fuel-type classification of the study area vegetation is based on the standard fuel types of the Canadian Forest Fire Behavior Prediction System. Note: fuel types totaling < 1% have not been reported in this figure.

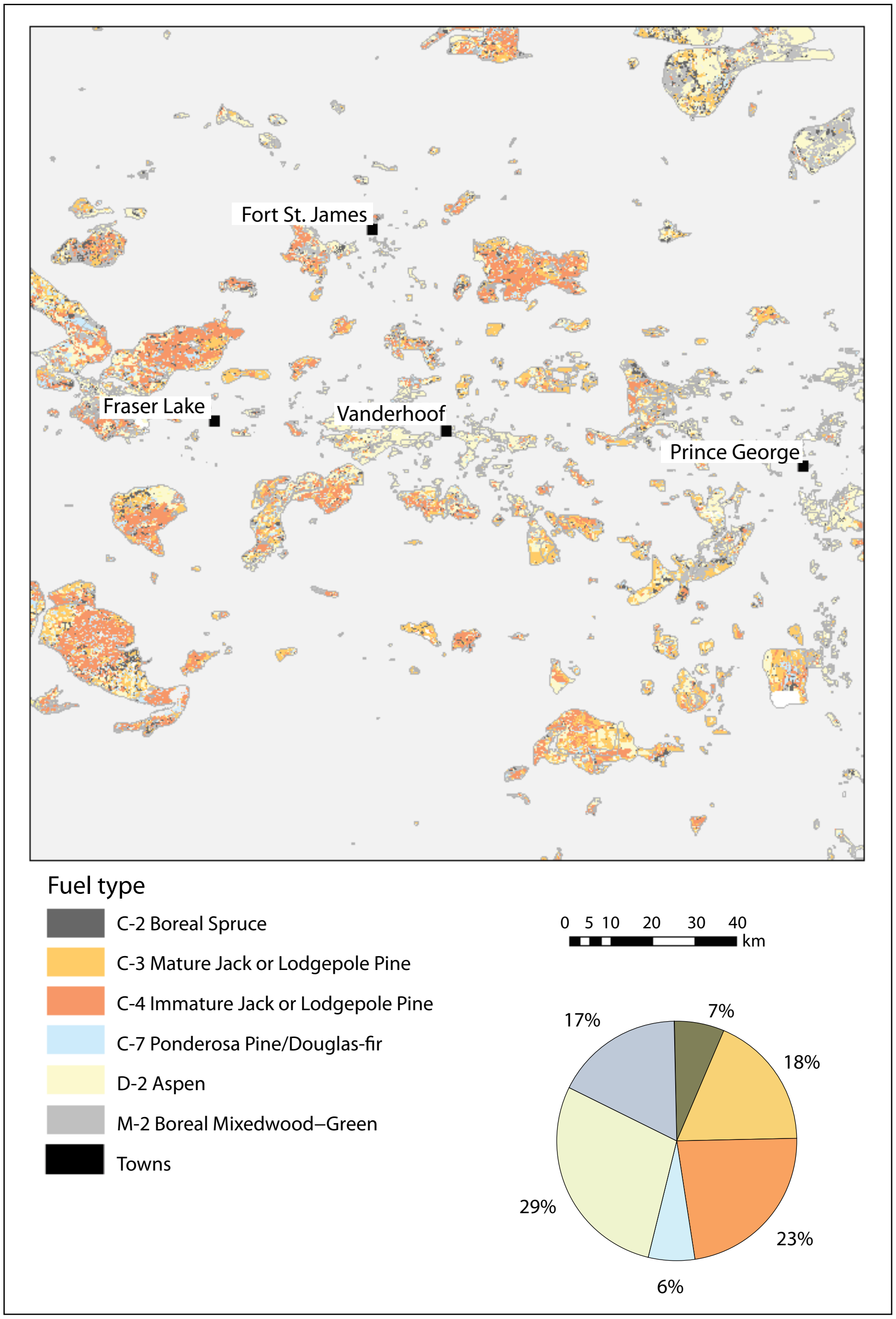

Figure A2.15. **Fuel-type classification of areas within the study area that were burned by fires before 1950.** Fuel-type classification of the study area vegetation is based on the standard fuel types of the Canadian Forest Fire Behavior Prediction System. Note: fuel types totaling < 1% have not been reported in this figure.

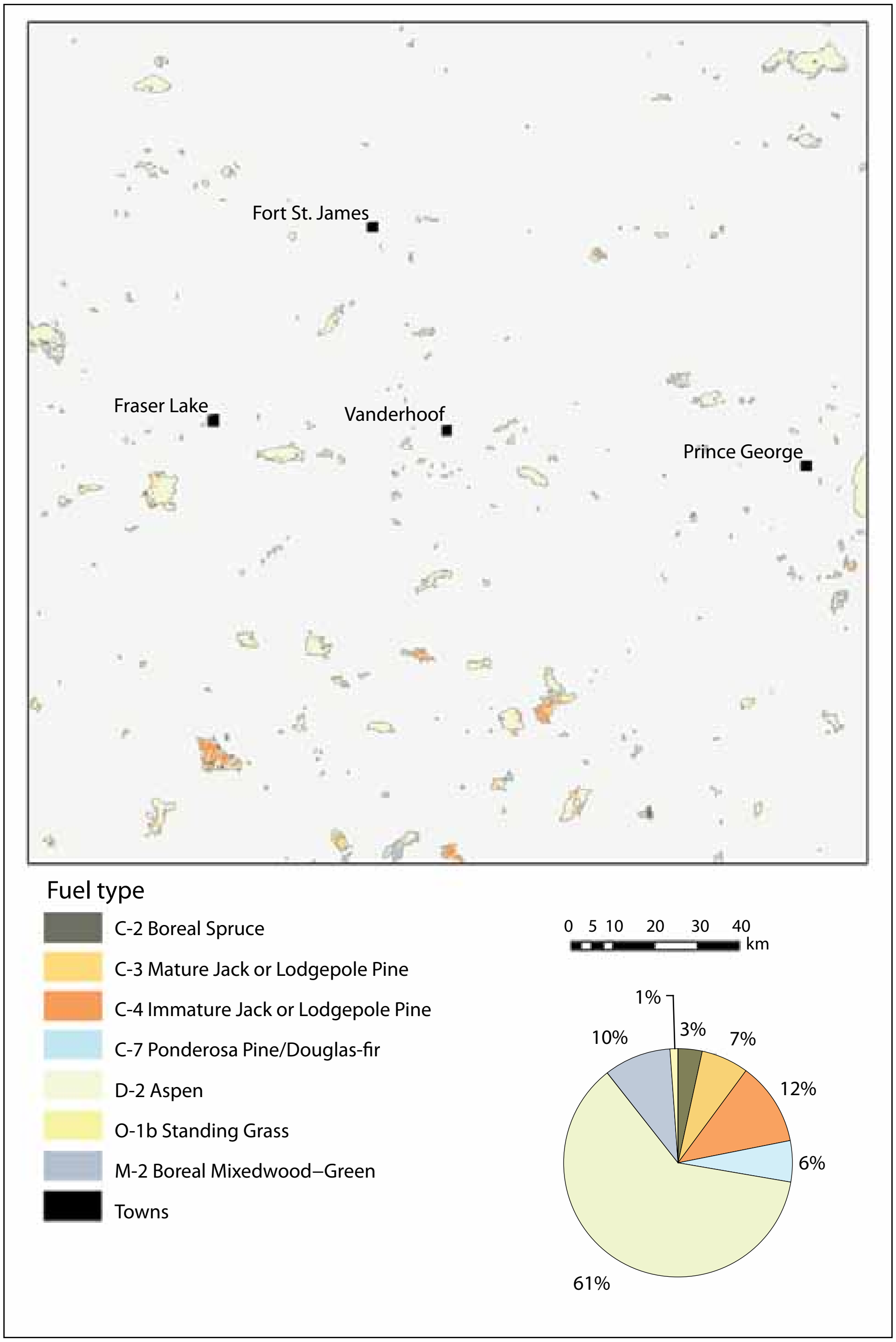

Figure A2.16. **Fuel-type classification of areas within the study area that were burned by fires after 1950.** Fuel-type classification of the study area vegetation is based on the standard fuel types of the Canadian Forest Fire Behavior Prediction System.

These missing records were due to variations in the timing of spring activation of the weather stations. After all substitutions were made, >98% of fire-season days were represented for all stations.

Fire growth simulations with Prometheus require components of the Canadian Forest Fire Weather Index (FWI) System as inputs. When fire weather stations are activated in the spring, start-up values are used to initiate the FWI calculations. To ensure consistency between the baseline historical weather and predicted weather, FWI System components were calculated from default spring start-up values for all stations (Fine Fuel Moisture Code [FFMC] = 85, Duff Moisture Code = 8, and Drought Code = 50), based on a start date of 1 May.

BURN-P3 simulates only fires that have significant impacts on the landscape. These large (escaped) fires tend to occur under exceptionally warm and dry fire weather conditions, and the weather files used in the BURN-P3 model represent only these extreme fire weather conditions. When a fire is simulated in BURN-P3, a single weather record is drawn from the pool of available records and then is used by Prometheus to grow the fire. Separate fire weather pools are created for the spring and summer seasons, with each record representing peak daily burning conditions for a single spread-event day. For simulated fires with multiple spread-event days, a unique weather record is drawn for each day.

To produce a fire weather pool for each season, the records were divided into spring and summer subsets and were then sorted by the FWI System components determined to be most relevant to the spread of large fires in the Vanderhoof study area. The top 10% of records were then selected for inclusion in the BURN-P3 weather pools. Local fire management experts were consulted to help in determining the most significant FWI System components relevant to large fire activity. Elevated values for FFMC

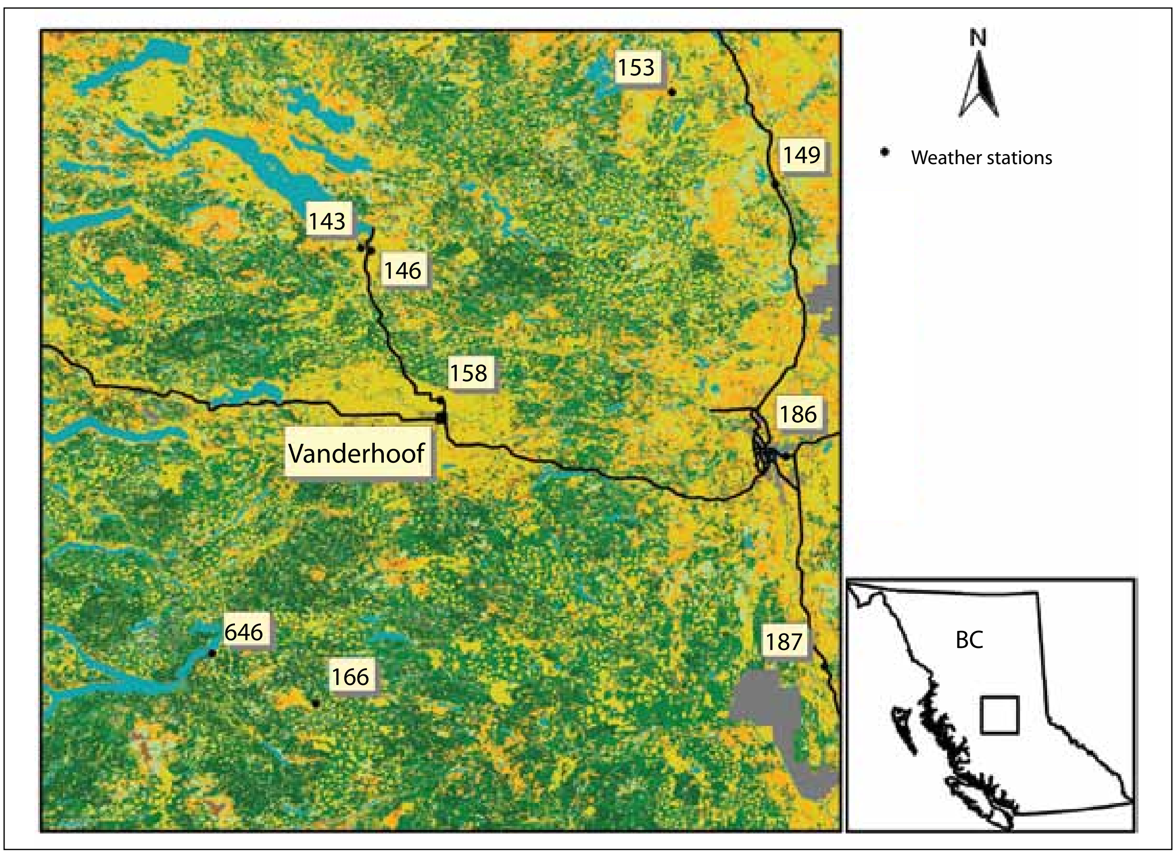

Figure A2.17. Location of primary and secondary weather stations within the Vanderhoof study area. Secondary stations are 153, 143, and 646.

Table A2.4. Summary of weather-record substitutions used to complete missing records for primary stations

Primary station	Source station for substitute record	Records substituted
146	143	1 May 1984 to 8 July 1991
	158	26 May 2004
149	153	15 May to 5 June 1995
	153	2–4 May 2000
	153	11–27 May 2002
	153	28 May 2004
158	153	20 May 2004
166	646	1–14 May 1995
186	NA[a]	No substitutions
187	186	12 July to 4 August 1998

[a]NA = not applicable.

Table A2.5. Summary of days missing from historical weather stream

Primary station	Period missing	No. of days missing
146	1–5 May 1996	5
149	1–6 May 1985	6
149	1–7 May 1986	7
149	1–3 May 1987	3
149	1–5 May 1988	5
149	1–2 May 1989	2
149	1–3 May 1990	3
149	1 May 1991	1
149	1–5 May 1992	5
149	1–15 May 1995	15
149	1 May 2000	1
149	1–10 May 2002	10
166	1–18 May 1985	18
166	1–3 May 1994	3
166	1–5 May 1996	5
166	1–14 May 1997	14
166	1–8 May 1999	8
166	1–7 May 2002	7
187	1 May 1991	1
187	1–3 May 2001	3
Total		122

and Initial Spread Index (ISI) were identified as important indicators of large-fire activity in the study area. For each season, weather records were sorted by FFMC and then by ISI to extract the top 10% of records for inclusion in the BURN-P3 pools.

Predicted Weather

Two of the BURN-P3 scenarios required weather inputs representative of future conditions in the period 2041–2060. For one scenario, current weather conditions were assumed to be representative of conditions expected between 2041 and 2060, a relatively optimistic assumption. The second future scenario involved prediction of future weather under conditions of climate change. For this scenario, baseline weather data for the period 1985–2002 were adjusted using outputs from climate change models to produce weather pools under a warmer climate.

Future weather scenarios were predicted by three different general circulation models: the Canadian Second-Generation Coupled Global Climate Model (CGCM2), the Hadley Centre Third-Generation Coupled Model (HadCM3, developed by the UK Hadley Centre; http://www.metoffice.com/research/hadleycentre/index.html), and the Commonwealth Scientific and Industrial Research Organization (CSIRO) Mark 2 model (CSIRO Mk2),[2] developed by the CSIRO's Atmospheric Research Laboratory (http://www.csiro.au). For all three models, two emissions scenarios were used (the A2 and B2 scenarios of the *Special Report on Emissions Scenarios*),[3] for a total of six future fire weather scenarios.[4] Data from all models were available in grid format, although the grids differed among the models. Weather variables for each model were interpolated to a resolution of 10 km. Grid points within the study area were used to produce monthly average values for a set of weather variables (Table A2.6).

The daily FWI System components required by BURN-P3 are produced from fire weather variables (dry-bulb temperature, relative humidity, 10-m open wind speed, and 24-h precipitation) recorded at noon local standard time. Daily GCM projections suitable for fire weather calculations were not readily available, so daily values were approximated from monthly GCM data using a method described by Flannigan and Van Wagner (1991).[5] The approach involves calculating mean monthly variations in climate model outputs relative to baseline conditions and then adjusting the daily baseline weather records to account for the differences. Adjusting historical daily records allows the preservation of natural patterns in day-to-day variability, which may or may not be consistent with future variability under climate change.

Adjustments were made to baseline temperature, wind speed, and precipitation, but relative humidity and wind direction were not adjusted. Baseline weather variables were altered as follows:

$$t_f = t_b + (T_f - T_b)$$

$$ws_f = ws_b + ws_b\,[(WS_f - WS_b)/\,WS_b]$$

$$p_f = p_b + p_b\,[(P_f - P_b)/\,P_b]$$

where t, ws, and p are daily temperature, wind speed, and precipitation, respectively, and T, WS, and P are mean monthly temperature, wind speed and precipitation. The subscripts f and b denote future and baseline measurements.

FWI System values were calculated from these adjusted weather variables with the same

[2]At the time of this study, only the results of the CSIRO Mark 2 GCM were available. The current version of the model is CSIRO Mark 3.5. For further information, refer to the following link: http://www-pcmdi.llnl.gov/ipcc/model_documentation/CSIRO-Mk3.5.htm.

[3]Nakicenovic, N.; Swart, R., editors. 2000. Special report on emissions scenarios. A special report of Working Group III of the Intergovernmental Panel on Climate Change. Cambridge Univ. Press, Cambridge, UK. Also available at http://www.ipcc.ch/ipccreports/sres/emission/index.htm accessed 9 April, 2008.

[4]A2 = scenario with a regionalized global economy in which the rate of increase in greenhouse gas emissions is comparable to the rate of increase in the 1990s. B2 = scenario with a regionalized global economy in which societies are more socially and environmentally conscious than in scenario A2, with slower population growth, lower energy intensity, and less reliance on fossil fuels, leading to a much lower rate of growth in greenhouse gas emissions.

[5]Flannigan, M.D.; Van Wagner, C.E. 1991. Climate change and wildfire in Canada. Can. J. For. Res. 21:66–72.

default start-up values used to calculate the baseline FWI System components. Comparisons of fire weather predicted by each CGM were used to select a single GCM for use in BURN-P3 modeling. Weather pools were created using the same methods that were used for extracting baseline weather records.

Predicted Escaped Fires

An important input in the BURN-P3 model is the annual number of escaped fires (fires with a final size > 20 ha), which can be input as an average or a distribution. An average of three escaped fires per year was used, reflecting historical fire activity in the study area over the period 1970–2002. To predict the number of escaped fires per year under conditions of climate change, the historical relation between the proportion of days in a fire season characterized by critical fire weather and the number of escaped fires per year was examined. Weather conditions characterized by extreme FWI System components relevant to the spread of large fires (i.e., FFMC, ISI, and FWI) were explored. There was a strong positive correlation (R^2 = 0.76) between the number of escaped fires per year and the proportion of fire season days with an ISI value ≥ 20 or an FWI value ≥ 46. Predicted future increases in the proportion of fire season days with these critical values ranged from 31% to 118% for the 6 climate change scenarios (Table A2.7). Simple linear regression was used to predict the number of escaped fires expected under each of the six GCM models (Table A2.7).

The results suggest that the number of escaped fires could increase by as much as 100% with climate change, although they do not account for potential future changes in vegetation or other factors that could either limit or increase the potential for escaped fires. This statistical model is extremely weak (R^2 = 0.58), but it represents the best available approach for adjusting the BURN-P3 escaped-fire input and was considered acceptable for the purposes of this study.

Selection of a General Circulation Model

All six GCMs predicted increases in critical fire weather for the period 2041–2060. The model with the most dramatic increases was chosen for low-flammability with climate change scenario in BURN-P3. This scenario assumes an optimistic outcome for future fuel conditions, but a pessimistic outcome for future climate. The CGCM2 forced by the B2 emissions scenario was selected because it produced the most extreme changes in fire weather (Table A2.7). The other future weather scenarios were not used in spatial BURN-P3 simulations.

Table A2.6. Monthly weather variables obtained from each global climate model

CGCM2 (A2 and B2)[a, b, c]	HadCM3 (A2 and B2)[d]	CSIRO Mk2 (A2 and B2)[e]
Screen (2-m) temperature (°C) Mean daily maximum screen temperature (°C) Mean daily minimum screen temperature (°C) Screen specific humidity (kg/kg) Mean 2-m wind speed (m/s) Precipitation (mm/day)	2-m mean surface air temperature (K) Total precipitation (mm/d) Mean scalar wind speed (m/s) Humidity (%)	2-m mean surface air temperature (K) 2-m mean maximum air temperature (K) 2-m mean minimum air temperature (K) Total precipitation (mm/d) Mean scalar wind speed (m/s)

[a]CGCM2 = Canadian Second-Generation Coupled Global Climate Model. Data obtained from <http://www.cccma.bc.ec.gc.ca/data/cgcm2/cgcm2.shtml>.
[b]A2 = scenario with a regionalized global economy in which the rate of increase in greenhouse gas emissions is comparable to the rate of increase in the 1990s.
[c]B2 = scenario with a regionalized global economy in which societies are more socially and environmentally conscious than in scenario A2, with slower population growth, lower energy intensity, and less reliance on fossil fuels, leading to a much lower rate of growth in greenhouse gas emissions.
[d]HadCM3 = Hadley Centre Third-Generation Coupled Model. Data obtained from <http://www.mad.zmaw.de/IPCC_DDC/html/SRES_TAR/index.html>.
[e]CSIRO Mk2 = Commonwealth Scientific and Industrial Research Organization Mark 2 model. Data obtained from <http://www.mad.zmaw.de/IPCC_DDC/html/SRES_TAR/index.html>.

Table A2.7. Predicted future increases in proportion of fire season days with critical fire weather[a] and predicted number of escaped fires per year for the period 2041–2061

Scenario	Predicted increase in proportion of days with critical fire weather (%)	Predicted no. of escaped fires per year
CGCM2–A2[b, c]	31.0	4
CGCM2–B2[d]	118.0	6
CSIRO Mk2–A2[e]	110.7	6
CSIRO Mk2–B2	99.7	6
HadCM3–A2[f]	51.0	4
HadCM3–B2	82.3	5

[a]Critical fire weather is defined as Initial Spread Index ≥ 20 or Fire Weather Index ≥ 46.
[b]CGCM2 = Canadian Second-Generation Coupled Global Climate Model.
[c]A2 = scenario with a regionalized global economy in which the rate of increase in greenhouse gas emissions is comparable to the rate of increase in the 1990s.
[d]B2 = scenario with a regionalized global economy in which societies are more socially and environmentally conscious than in scenario A2, with slower population growth, lower energy intensity, and less reliance on fossil fuels, leading to a much lower rate of growth in greenhouse gas emissions.
[e]CSIRO Mk2 = Commonwealth Scientific and Industrial Research Organization Mark 2 model.
[f]HadCM3 = Hadley Centre Third-Generation Coupled Model.

APPENDIX 3

GENERAL BACKGROUND ABOUT SCENARIO ANALYSIS

Qualitative analysis of socioeconomic scenarios is a form of exploratory analysis that has emerged from the future studies literature. It involves a participatory brainstorming process to identify key factors, driving forces, and critical uncertainties in order to create “stories” about potential alternative futures.[1] This methodology emerged in response to the limitations of quantitative or formal modeling methods. For example, econometric and statistical techniques often ignore qualitative perspectives and fail to account for discontinuities. Economic models have limited accuracy with respect to their ability to make predictions over long periods, especially where there are changes in social constructs over the prediction period.

Qualitative scenario analysis can be viewed as either an alternative to quantitative modeling or a complementary approach. For example, a broad exploratory process can be used to identify and organize perceptions about alternative futures and to help identify some of the key drivers that should be included in a narrower quantitative modeling exercise. This is particularly useful as a way of rejecting futures that are intuitively unlikely, even if, on a statistical basis, they appear to deserve equal weight. Alternatively, numeric scenario outcomes could be used as examples of alternative futures in an assessment of the perceptions surrounding those specific outcomes and to stimulate broader discussion.

Socioeconomic scenarios are an important component of vulnerability assessments.[2] There are five main reasons for developing socioeconomic scenarios as part of an assessment of a community’s vulnerability to climate:

- To provide a basis for understanding vulnerability to climate impacts in the context of vulnerability to other forces. Communities may be vulnerable to climate and to climate change, but this may be less important than their vulnerability to some other external pressure. Alternatively, other factors may exacerbate the degree to which a community is vulnerable to climate-related effects.
- To provide a baseline for assessing potential net economic impacts of climate change. One way to assess the sensitivity of the local economy to climate effects is to evaluate future potential flows of economic benefits under different climate scenarios. Assessing net impacts often involves comparing the various scenarios to a baseline case. However, in many cases the baseline is itself evolving over time. Thus, a socioeconomic scenario can provide insights about expected trends in the baseline.
- To provide sector-specific outlooks for locally important industries. For example, climate change will likely 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 local community levels.
- To provide a structured approach for obtaining expert local knowledge about community futures. Scenario development may involve obtaining information and feedback from local experts and stakeholders.
- To provide an organizing framework for integrating biophysical and socioeconomic analysis for the purposes of providing a comprehensive assessment of climate change impacts and sources of vulnerability (see the section of the main report entitled “Summary and Conclusions”).

[1]Bell, W. 1997. Foundations of future studies: human science for a new era. Transaction Publishers, New Brunswick, NJ.
[2]Shackley, S.; Deanwood, R. 2003. Constructing social futures for climate-change impacts and response studies: building qualitative and quantitative scenarios with the participation of stakeholders. Clim. Res. 24:71–90.

APPENDIX 4

PROJECTIONS OF INCREMENTS IN STEMWOOD

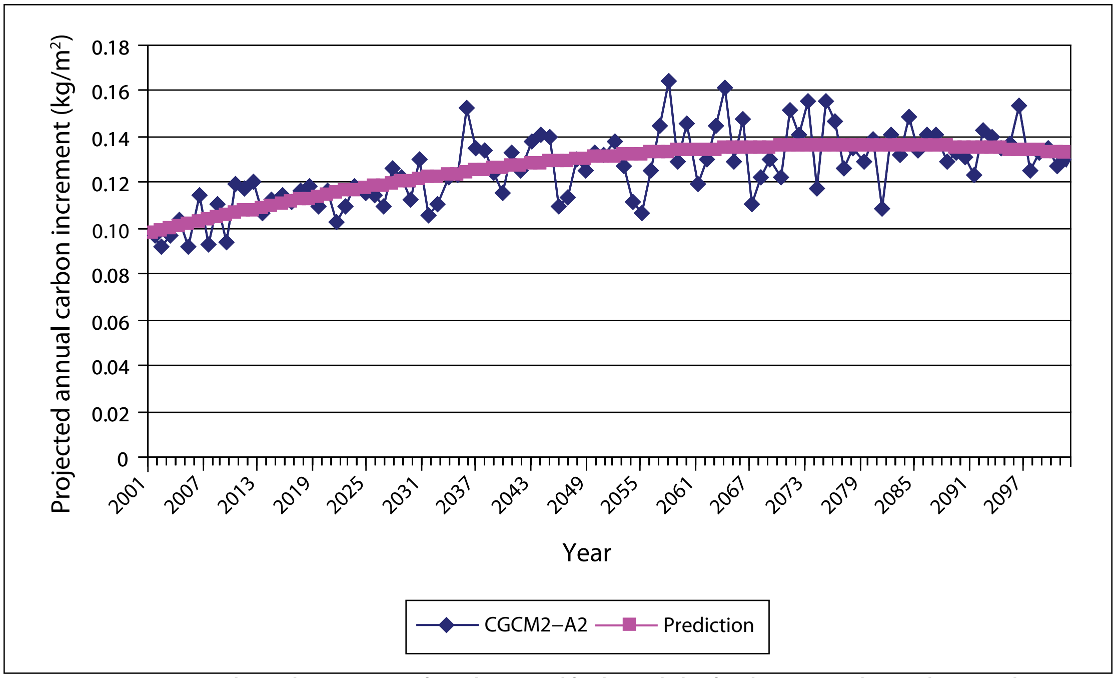

Figure A4.1. **Projected annual increment in softwood stemwood for the Vanderhoof study area using the Canadian Second-Generation Coupled Global Climate Model (CGCM2) with the A2 scenario, in which the rate of increase in greenhouse gas emissions is comparable to the rate of increase in the 1990s.**

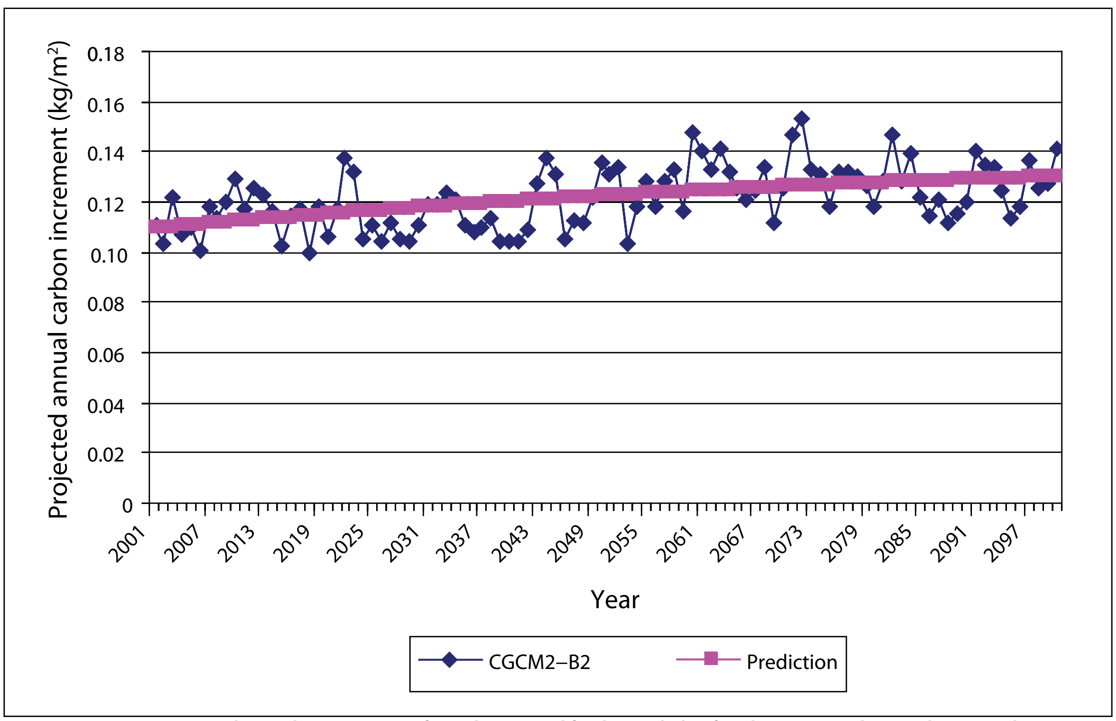

Figure A4.2. **Projected annual increment in softwood stemwood for the Vanderhoof study area using the Canadian Second-Generation Coupled Global Climate Model (CGCM2) with the B2 scenario, in which societies are more socially and environmentally conscious than in scenario A2, with slower population growth, lower energy intensity, and less reliance on fossil fuels, leading to a much lower rate of growth in greenhouse gas emissions.**

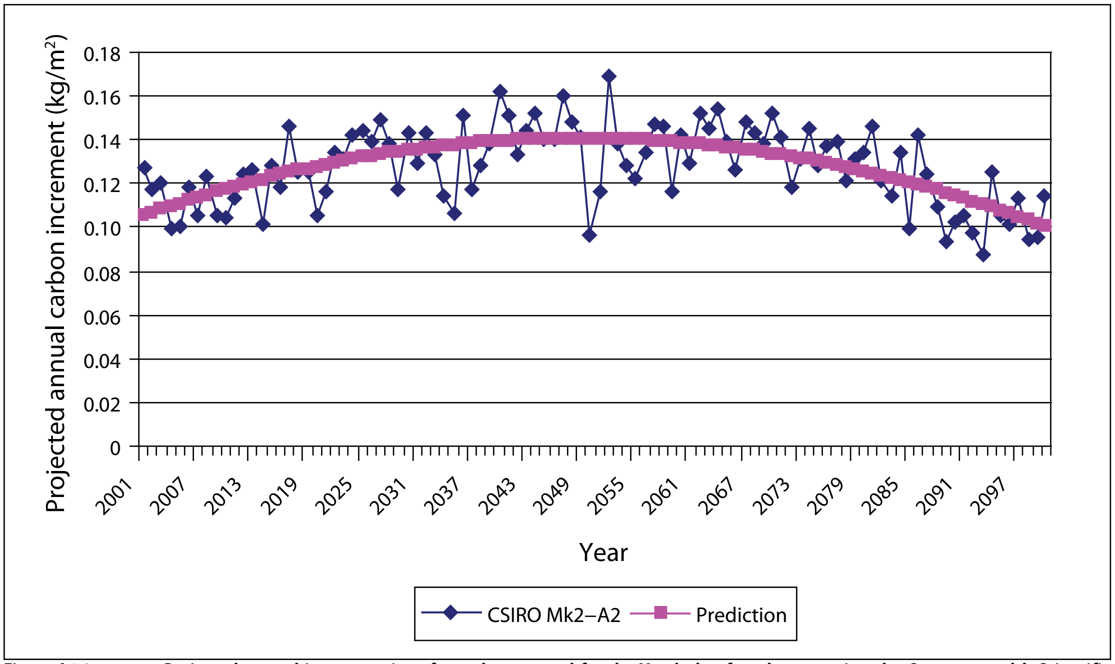

Figure A4.3. Projected annual increment in softwood stemwood for the Vanderhoof study area using the Commonwealth Scientific and Industrial Research Organization Mark 2 model (CSIRO Mk2) with the A2 scenario, in which the rate of increase in greenhouse gas emissions is comparable to the rate of increase in the 1990s.

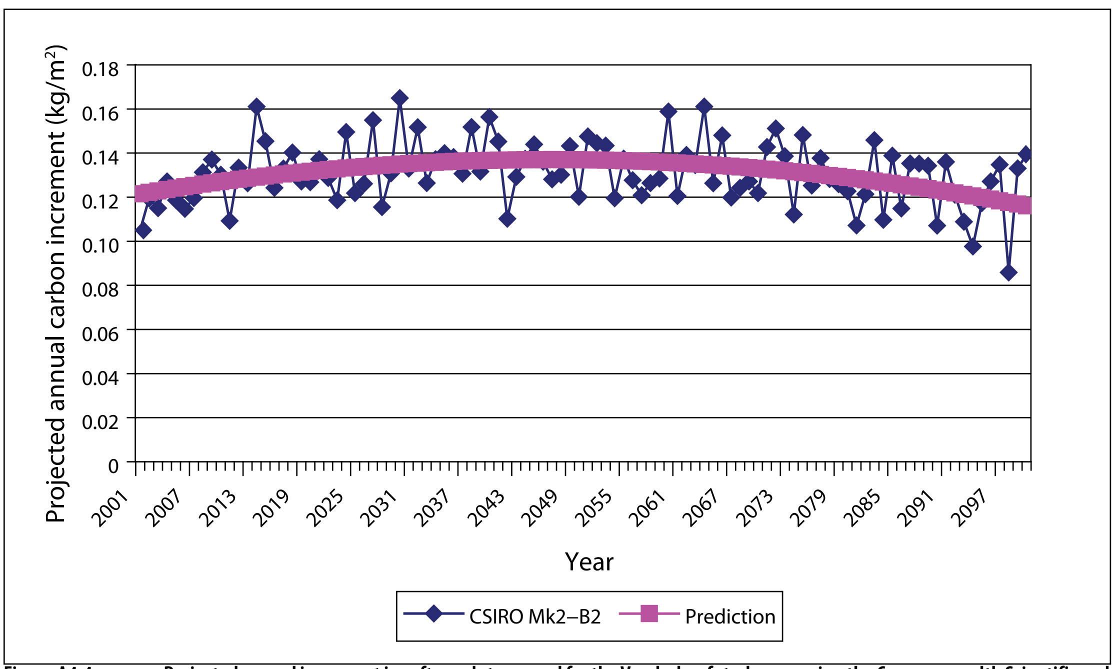

Figure A4.4. Projected annual increment in softwood stemwood for the Vanderhoof study area using the Commonwealth Scientific and Industrial Research Organization Mark 2 model (CSIRO Mk2) with the B2 scenario, in which societies are more socially and environmentally conscious than in scenario A2, with slower population growth, lower energy intensity, and less reliance on fossil fuels, leading to a much lower rate of growth in greenhouse gas emissions.

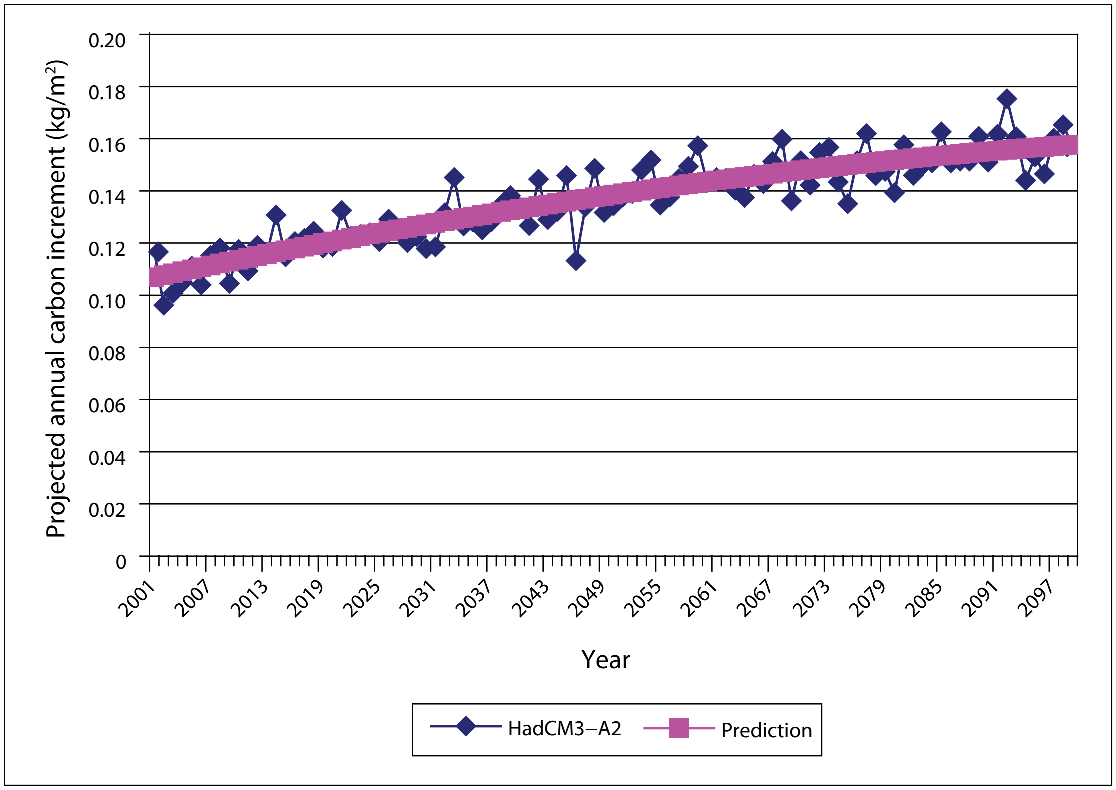

Figure A4.5. Projected annual increment in softwood stemwood for the Vanderhoof study area using the Hadley Centre Third-Generation Coupled Model (HadCM3) with the A2 scenario, in which the rate of increase in greenhouse gas emissions is comparable to the rate of increase in the 1990s.

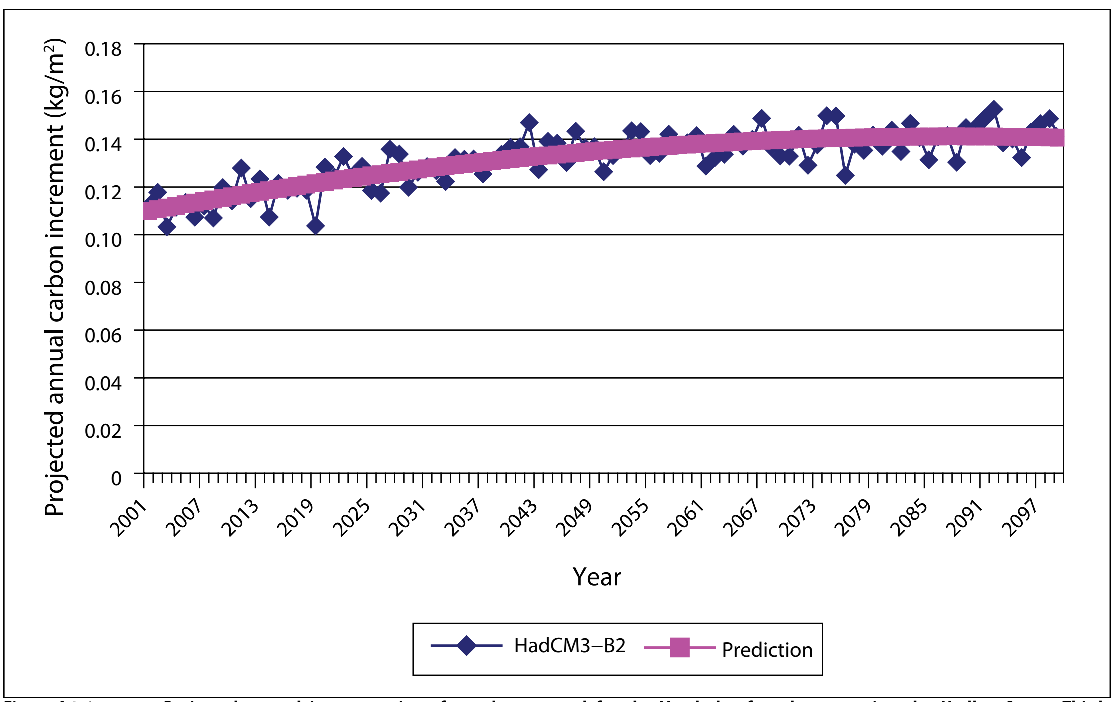

Figure A4.6 Projected annual increment in softwood stemwood for the Vanderhoof study area using the Hadley Centre Third-Generation Coupled Model (HadCM3) with the B2 scenario, in which societies are more socially and environmentally conscious than in scenario A2, with slower population growth, lower energy intensity, and less reliance on fossil fuels, leading to a much lower rate of growth in greenhouse gas emissions.

APPENDIX 5

THE COMPUTABLE GENERAL EQUILIBRIUM MODEL

Computable general equilibrium (CGE) models are used to assess the economy-wide impacts (in terms of changes in variables such as employment and income) of shocks to a particular economy. Appendix 5 provides the structure of the CGE model used for this study. The basic model was taken from a previous study, which investigated the impacts of the mountain pine beetle on the economy of the Prince George area.[1] For modeling purposes the boundary of the Prince George area economy was assumed to be the same as the boundary of the Prince George Timber Supply Area, and the economy was defined as having six sectors: agriculture, forestry, services, public, visitor, rest of economy. The first step in assessing local economic impacts was to simulate the impacts of climate change on the local timber supply around 2050. This entailed determining productivity effects multipliers (by means of the Canadian Integrated Biosphere Simulator), which were then used to adjust projections of timber harvest potential. The relative change in timber supply was assumed to result in the same relative change in exports from the forestry sector of the economy. Percent changes in income and employment between 2000 and 2055 were simulated under two model closure rules (fixed- and flexible-wage assumptions). Tables A5.3 and A5.4 provide the detailed results by sector and scenario.

[1]Patriquin, M.; Heckbert, S.; Nickerson, C.; Spence, M.; White, B. 2005. Regional economic implications of the mountain pine beetle infestation in the northern interior forest region of British Columbia. Nat. Resour. Can., Can. For. Serv., Pac. For. Cent., Victoria, BC. Mountain Pine Beetle Initiative Working Paper. 2005-3.

Table A5.1 Equations for generalized linear computable general equilibrium model

1.	$L_j = X_j - [W - (\alpha_W W + \alpha_{R^K} R_j^K + \alpha_{R^D} R_j^D)]$	j = sector 1, 2, …, 6[a]
2.	$K_j = X_j - [R^K{}_j - (\alpha_W W + \alpha_{R^K} R_j^K + \alpha_{R^D} R_j^D)]$	j = sector 1, 2, …, 6
3.	$D_j = X_j - [R^D{}_j - (\alpha_W W + \alpha_{R^K} R_j^K + \alpha_{R^D} R_j^D)]$	j = sector 1, 2, …, 6
4.	$X_{ij}^C = X_j$	i, j = sector 1, 2, …, 6
5.	$P_j = \sum_{i=1}^{6} \delta_{P^c} P_{ij}{}^C + (\delta_W W_j + \delta_{R^K_j} R_j^K + \delta_{R^D_j} R_j^D + \delta_{PM} \mathrm{PM}_j + \delta_{GT} \mathrm{GT}_j)$	i, j = sector 1, 2, …, 6
6.	$X_j^F = Y - P_j$	j = sector 1, 2, …, 6
7.	$\mathrm{ELF} = \sum_{j=1}^{6} \beta_j L_j$	j = sector 1, 2, …, 6
8.	$X_j = \sum_{i=1}^{6} \varphi X^C{}_{ij} + \eta X^F{}_i + \theta E_j + \eta_G G_i$	j = sector 1, 2, …, 5
		i = sector 1, 2, …, 6
9.	$E_j = -\phi(P_j - W_j^P + \mathrm{ER})$	j = sector 1, 2, …, 5
10.	$Y = \lambda_W \mathrm{ELF}_j + \lambda_W W + \lambda_{R^K} K_j + \lambda_{R^K} R^K{}_j + \lambda_{R^D} D_j + \lambda_{R^D} R^D{}_j + \lambda_G G$	j = sector 1, 2, …, 6

[a]Sector 6 – the “rest of the economy” is specified as nonexporting.
Source: Patriquin, M.N.; Lantz, V.; Furtas, R.; Ambard, M. ; White, W.A. 2007. Socioeconomic transition in the Foothills Model Forest from 1996 to 2001. Nat. Resour. Can., Can. For. Serv., North. For. Cent., Edmonton, AB and Foothills Model Forest, Hinton, AB. Inf. Rep. NOR-X-410. Reprinted with permission.

Table A5.2 Model variables and parameters

Variable or parameter	Definition
Endogenous variables	
L	Labor
X	Output
R^K	Rental rate of capital
R^D	Rental rate of land
X^F	Final demand for output
X^C	Intermediate demand for output
Y	Household income
P	Domestic price of output
W^P[a]	World price of output
ELF[b]	Employed labor force
P^C[b]	Intermediate outprice price
Exogenous variables	
K	Capital
D	Land
E[a]	Exports
ER	Foreign exchange rate
G	Government expenditure
PM	Price of imports
GT	Indirect taxes
W	Wage rate
Parameters	
α	Factor share
β	Employed labor force share
φ	Intermediate demand share
η	Final demand share
θ	Export share
η_G	Government demand share
δ	Primary and intermediate input cost share
ϕ	Factor share of export demane
λ	Factor income share

[a]Sector 2 – "Forestry" is specified with W^P (endogenous) and E (exogenous) in order to use exports as a proxy for timber supply.
[b]If W is endogenous, ELF is exogenous and vice versa.

Table A5.3. Simulated labor income with fixed-wage assumption

Scenario[a]	Sector labor income	Baseline level ($ million)	Traditional uplift[b] (% change)	Nontraditional uplift (% change)	Maximum fall-down[c] (% change)	Simulation end (% change)
mpb1nc	Agriculture	19.53	1.36	2.61	−0.73	−0.57
	Forestry	346.19	33.62	64.84	−18.15	−14.19
	Services	294.54	7.01	13.52	−3.79	−2.96
	Public	450.66	2.37	4.57	−1.28	−1.00
	Visitor	108.55	2.02	3.90	−1.09	−0.85
	ROE[d]	385.79	4.91	9.47	−2.65	−2.07
	Total	1605.26	10.53	20.32	−5.69	−4.45
mpb2nc	Agriculture	19.53	1.36	3.82	−0.96	−0.96
	Forestry	346.19	33.62	94.86	−23.77	−23.77
	Services	294.54	7.01	19.78	−4.96	−4.96
	Public	450.66	2.37	6.69	−1.68	−1.68
	Visitor	108.55	2.02	5.70	−1.43	−1.43
	ROE	385.79	4.91	13.85	−3.47	−3.47
	Total	1605.26	10.53	29.72	−7.45	−7.45
mpb1c1	Agriculture	19.53	1.36	2.61	−0.65	0.67
	Forestry	346.19	33.62	64.84	−16.17	16.70
	Services	294.54	7.01	13.52	−3.37	3.48
	Public	450.66	2.37	4.57	−1.14	1.18
	Visitor	108.55	2.02	3.90	−0.97	1.00
	ROE	385.79	4.91	9.47	−2.36	2.44
	Total	1605.26	10.53	20.32	−5.07	5.23
mpb1c2	Agriculture	19.53	1.36	2.61	−0.65	0.26
	Forestry	346.19	33.62	64.84	−16.17	6.51
	Services	294.54	7.01	13.52	−3.37	1.36
	Public	450.66	2.37	4.57	−1.14	0.46
	Visitor	108.55	2.02	3.90	−0.97	0.39
	ROE	385.79	4.91	9.47	−2.36	0.95
	Total	1605.26	10.53	20.32	−5.07	2.04
mpb2c1	Agriculture	19.53	1.36	3.82	−0.96	−0.18
	Forestry	346.19	33.62	94.86	−23.77	−4.57
	Services	294.54	7.01	19.78	−4.96	−0.95
	Public	450.66	2.37	6.69	−1.68	−0.32
	Visitor	108.55	2.02	5.70	−1.43	−0.27
	ROE	385.79	4.91	13.85	−3.47	−0.67
	Total	1605.26	10.53	29.72	−7.45	−1.43

Table A5.3. Simulated labor income with fixed wage assumption (concluded)

Scenario[a]	Sector labor income	Baseline level ($ million)	Traditional uplift[b] (% change)	Nontraditional uplift (% change)	Maximum fall-down[c] (% change)	Simulation end (% change)
mpb2c2	Agriculture	19.53	1.36	3.82	−0.96	−0.53
	Forestry	346.19	33.62	94.86	−23.77	−13.09
	Services	294.54	7.01	19.78	−4.96	−2.73
	Public	450.66	2.37	6.69	−1.68	−0.92
	Visitor	108.55	2.02	5.70	−1.43	−0.79
	ROE	385.79	4.91	13.85	−3.47	−1.91
	Total	1605.26	10.53	29.72	−7.45	−4.10

[a]mpb1nc = best-case mountain pine beetle scenario with no climate change, mpb2nc = worst-case mountain pine beetle scenario with no climate change, mpb1c1 = best-case mountain pine beetle scenario with best-case climate change, mpb1c2 = best-case mountain pine beetle scenario with worst-case climate change, mpb2c1 = worst-case mountain pine beetle scenario with best-case climate change, mpb2c2 = worst-case mountain pine beetle scenario with worst-case climate change.
[b]uplift = temporary increase in harvest to accommodate salvage of beetle-killed trees.
[c]fall-down = reduction in potential harvest following the salvage period.
[d]ROE = rest of the economy.

Table A5.4. Simulated labor income with flexible-wage assumption

Scenario[a]	Sector labor income	Baseline level ($ million)	Traditional uplift[b] (% change)	Nontraditional uplift (% change)	Maximum fall-down[c] (% change)	Simulation end (% change)
mpb1nc	Agriculture	19.53	−9.13	−17.60	4.93	3.85
	Forestry	346.19	14.26	27.50	−7.70	−6.02
	Services	294.54	0.57	1.09	−0.31	−0.24
	Public	450.66	−0.02	−0.05	0.01	0.01
	Visitor	108.55	−8.46	−16.32	4.57	3.57
	ROE[d]	385.79	−2.48	−4.78	1.34	1.05
	Total	1605.26	1.89	3.65	−1.02	−0.80
mpb2nc	Agriculture	19.53	−9.13	−25.75	6.45	6.45
	Forestry	346.19	14.26	40.23	−10.08	−10.08
	Services	294.54	0.57	1.60	−0.40	−0.40
	Public	450.66	−0.02	−0.07	0.02	0.02
	Visitor	108.55	−8.46	−23.88	5.99	5.99
	ROE	385.79	−2.48	−7.00	1.75	1.75
	Total	1605.26	1.89	5.34	−1.34	−1.34
mpb1c1	Agriculture	19.53	−9.13	−17.60	4.39	−4.53
	Forestry	346.19	14.26	27.50	−6.86	7.08
	Services	294.54	0.57	1.09	−0.27	0.28
	Public	450.66	−0.02	−0.05	0.01	−0.01
	Visitor	108.55	−8.46	−16.32	4.07	−4.20
	ROE	385.79	−2.48	−4.78	1.19	−1.23
	Total	1605.26	1.89	3.65	−0.91	0.94
mpb1c2	Agriculture	19.53	−9.13	−17.60	4.39	−1.77
	Forestry	346.19	14.26	27.50	−6.86	2.76
	Services	294.54	0.57	1.09	−0.27	0.11
	Public	450.66	−0.02	−0.05	0.01	0.00
	Visitor	108.55	−8.46	−16.32	4.07	−1.64
	ROE	385.79	−2.48	−4.78	1.19	−0.48
	Total	1605.26	1.89	3.65	−0.91	0.37
mpb2c1	Agriculture	19.53	−9.13	−25.75	6.45	1.24
	Forestry	346.19	14.26	40.23	−10.08	−1.94
	Services	294.54	0.57	1.60	−0.40	−0.08
	Public	450.66	−0.02	−0.07	0.02	0.00
	Visitor	108.55	−8.46	−23.88	5.99	1.15
	ROE	385.79	−2.48	−7.00	1.75	0.34
	Total	1605.26	1.89	5.34	−1.34	−0.26

Table A5.4. Simulated labor income with the flexible wage assumption (concluded)

Scenario[a]	Sector labor income	Baseline level ($ million)	Traditional uplift[b] (% change)	Nontraditional uplift (% change)	Maximum fall-down[c] (% change)	Simulation end (% change)
mpb2c2	Agriculture	19.53	−9.13	−25.75	6.45	3.55
	Forestry	346.19	14.26	40.23	−10.08	−5.55
	Services	294.54	0.57	1.60	−0.40	−0.22
	Public	450.66	−0.02	−0.07	0.02	0.01
	Visitor	108.55	−8.46	−23.88	5.99	3.29
	ROE	385.79	−2.48	−7.00	1.75	0.97
	Total	1605.26	1.89	5.34	−1.34	−0.74

[a]mpb1nc = best-case mountain pine beetle scenario with no climate change, mpb2nc = worst-case mountain pine beetle scenario with no climate change, mpb1c1 = best-case mountain pine beetle scenario with best-case climate change, mpb1c2 = best-case mountain pine beetle scenario with worst-case climate change, mpb2c1 = worst-case mountain pine beetle scenario with best-case climate change, mpb2c2 = worst-case mountain pine beetle scenario with worst-case climate change.
[b]uplift = temporary increase in harvest to accommodate salvage of beetle-killed trees.
[c]fall-down = reduction in potential harvest following the salvage period.
[d]ROE = rest of the economy.