

# Integrating climate change adaptation into forest management

by David L. Spittlehouse<sup>1</sup>

## ABSTRACT

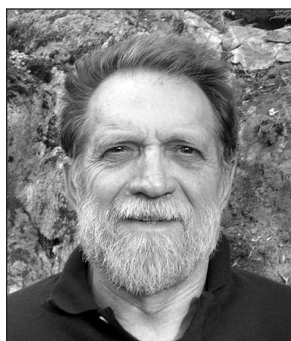
Future climate change will affect society's ability to use forest resources. We take account of climate in forest management and this will help us adapt to the effects of climate change on forests. However, society will have to adjust to how forests adapt by changing expectations for the use of forest resources because management can only influence the timing and direction of forest adaptation at selected locations. There will be benefits as well as losses and an important component of adaptation will be balancing values. Adaptation options to respond to impacts on the timber supply in Canada for the next 50 to 100 years are limited mainly to forest protection and wood utilisation because these forests are already in the ground. Adaptation through reforestation will focus on commercial tree species. It is important to start developing adaptation strategies now. These include assessing forest vulnerability to climate change, revising expectations of forest use, determining research and educational needs, development of forest policies to facilitate adaptation, and determining when to implement responses. Government agencies should take the lead in creating an environment to foster adaptation in forestry and in developing the necessary information required to respond.

**Key words:** climate change, impacts, adaptation, vulnerability, forests, ecosystems, risk management

## RÉSUMÉ

Les changements climatiques à venir affecteront la capacité de la société à profiter des ressources forestières. Nous prenons pour acquis les conditions climatiques en matière d'aménagement forestier et que cela nous permettra de s'adapter aux changements climatiques touchant les forêts. Cependant, la société devra s'ajuster en fonction de l'adaptation des forêts en modifiant les attentes au niveau de l'utilisation des ressources forestières parce que l'aménagement peut seulement influencer le moment et l'orientation de l'adaptation des forêts sur un site donné. Il y aura des bénéfices ainsi que des pertes et une forte proportion de l'adaptation proviendra de l'équilibre atteint entre les valeurs. Les possibilités d'adaptation pour répondre aux conséquences touchant l'approvisionnement en matière ligneuse au Canada pour les prochaines 50 à 100 années sont restreintes principalement à la protection des forêts et à l'utilisation de la matière ligneuse parce que ces forêts sont déjà en place. L'adaptation au moyen du reboisement se concentrera sur les espèces d'arbres à valeur commerciale. Il est important de commencer à élaborer des stratégies d'adaptation dès maintenant. On retrouve parmi celles-ci l'évaluation de la vulnérabilité des forêts face aux changements climatiques, la révision des attentes en matière d'utilisation des forêts, l'identification des besoins au niveau de la recherche et de l'éducation, l'élaboration de politiques forestières pour faciliter l'adaptation et l'identification du moment d'implantation des réponses. Les agences gouvernementales devraient prendre la direction de la création d'un environnement qui favorise l'adaptation en foresterie et de l'élaboration de l'information requise pour répondre aux questions sur le sujet.

**Mots clés :** changements climatiques, impacts, adaptation, vulnérabilité, forêts, écosystèmes, gestion du risque



David L. Spittlehouse

## Introduction

By the end of the 21<sup>st</sup> Century, the mean annual temperature for western North America could be 2–5°C above the range of temperatures that have occurred over the last 1000 years (Houghton *et al.* 2001). An increase in winter precipitation and a decrease in summer precipitation may also occur. These changes would significantly affect forest ecosystems and their utilization by society. Predicted changes include the movement of species ranges northward and up in elevation, new assemblages of species occurring in space and time, and changes in

disturbance regimes, forest productivity and water resources (Stewart *et al.* 1998, Kirschbaum 2000, Dale *et al.* 2001, Mote *et al.* 2003, Gray 2005, Hogg and Bernier 2005, Johnson and Williamson 2005, Volney and Hirsch 2005). Forest management decisions are usually based on the assumption that the climate remains relatively stable throughout a forest's life. This may have worked well in the past, but the prospect of future climate change challenges this assumption. Canada's natural resources and associated industries and communities are vulnerable to climate change and the forestry community need to be proactive in adapting to climate change (Davidson *et al.* 2003, Standing Senate Committee on Agriculture and Forestry 2003, Spittlehouse and Stewart 2003, Lazar 2005).

The climate is always changing and species and ecosystems have responded to these changes. The concern is that the future rate of change will be much faster than in the past and produce combinations of temperature and precipitation that

<sup>1</sup>Research Branch, BC Ministry of Forest, PO Box 9519, Stn. Prov. Govt., Victoria, British Columbia V8W 9C2. E-mail: dave.spittlehouse@gems4.gov.bc.ca

have no previous analogues. The resulting adjustment by forest species to the changing climate and accompanying disturbance regimes will challenge our ability to use forest resources. Consideration of weather and climate is part of forest management, and we may already be using many of the techniques necessary to adapt to climate change. For example, fire protection activities include calculating drought codes and developing fire smart communities (Dale *et al.* 2001, Volney and Hirsch 2005). Ecosystem mapping for forest management is climatically based (Pojar *et al.* 1987). Geographically based seed zones are areas of similar climate; provenance trials can be used to define climatic limits of trees (Rehfeldt *et al.* 1999, Parker *et al.* 2000, Rainville and Beaulieu 2005). Site preparation and stand management techniques are often designed to ameliorate climatic conditions (Lavender *et al.* 1990). Winter roads and harvesting where snow protects the land from damage are adaptations to climate (Pollard 1991).

My objective for this paper is to review the challenges to responding to climate change and present suggestions for integrating adaptation into forest management. I hope this will encourage the forestry community to begin assessing its vulnerability to climate change and developing options for adaptation.

### **Adapting to Climate Change in Forestry – Challenges**

Adaptation to climate change refers to adjustments in ecological, social, and economic systems in response to the effects of changes in climate (Smit and Pilifosova 2002, Davidson *et al.* 2003). Adaptive actions reduce the risks (decrease vulnerability) by preparing for adverse effects and capitalizing on the benefits. Although forest ecosystems will adapt autonomously, their importance to society means that we will want to influence the direction and timing of this adaptation at some locations. There are numerous challenges to adaptation, not the least of which is the uncertainty in the magnitude and timing of future climate change. This is compounded by the uncertainty in the future markets for our forest resources and global competition (Sohnngen and Sedjo 2005). The development of adaptation measures for some time in the future, under an uncertain climate, in an unknown socio-economic context is bound to be highly speculative (Burton *et al.* 2002). Some groups may view responding as a greater risk than doing nothing or that impacts can only be dealt with when they happen. There is a lack of awareness in the forestry community of the risks of climate change (Williamson *et al.* 2005). Consequently, we may have difficulty finding the desire and resources for adaptation.

Another major challenge is our limited knowledge of our vulnerability to climate change. Vulnerability is the degree to which a system (organism, ecosystem, company, or community) is susceptible to or unable to cope with climate change. Different systems are vulnerable to different aspects of change and what may be detrimental to one system could be beneficial to another. Consequently, an important component of adaptation will be balancing different values. The vulnerability of forests and their users depends on a range of factors (Stewart *et al.* 1998, Dale *et al.* 2001, Davidson *et al.* 2003, Gray 2005). Internal factors include sensitivity to climate at an individual and population level, fecundity, life span, habitat requirements, distribution, entrenched societal values, existing forest policy, and the adaptive capacity of the system.

External factors include the magnitude and rate of climate change, frequency, timing and size of disturbances (e.g., fire, insects, disease, and harvest), competition by systems better adapted to the new climate and barriers to movement.

The size of the forested land base in most of Canada's provinces and territories means that much of the forest will have to adjust without human intervention. For example, about 62 Mha of the 95 Mha of British Columbia is forested. Of the forested area, there are 38 Mha in the non-timber harvest land base (includes parks, wilderness areas and areas with operational constraints) where forest management is mainly fire protection and conservation. The remaining 24 Mha, the timber harvest land base, is harvested at about 0.2 Mha per year. Consequently, we will be able to assist the adaptation of the forest on only a small part of the land base. Adaptation will focus on the major commercial tree species and perhaps a few animal species, while the majority of forest plants and animals will have to adapt as best they can. Any large-scale disturbances caused by climate change would be particularly difficult to address.

There are institutional and policy barriers to responding to climate change. For example, seed planning zones, reforestation standards and hydrologic and wildlife management guidelines are designed for the current climate regime. There are no requirements for adaptation strategies in forest management plans, nor are there guidelines and sufficient experienced personnel to aid such activities. There are many stakeholders whose different needs are supplied by forests and therefore have different vulnerabilities to climate change. Increased winter precipitation and earlier snowmelt would affect water management by changing the timing and size of peak flows, and increasing the risk of sediment transport to streams, reducing water quality and degrading fish habitat (Mote *et al.* 2003).

Is the management style of minimum intervention appropriate in the future for parks and wilderness areas (Scott and Lemieux 2005)? How can a changing climate and habitat be included in conservation and recovery programs for rare and endangered plant species that often have specialized environmental requirements and low genetic diversity? As part of a species range becomes unsuitable it may be unable to move into areas where the climate is suitable because of slow migration rates, unsuitable growing substrate or lack of habitat (Stewart *et al.* 1998, Gray 2005).

How will existing forests respond to the changing climate and what is the risk to the future timber supply? Most of the wood that will be harvested in Canada over the next 50 to 100 years will come from trees that are already growing or will be planted in the next decade with minimal climate change adaptation considerations. In some areas there will be an increase in forest productivity while in other areas there will be a decrease (Spittlehouse 2003, Hogg and Bernier 2005, Johnson and Williamson 2005). What will this mean for rotation ages, wood quality, wood volume, size of logs and determining the annual allowable cut? Access to timber and harvest scheduling will change because warming winters will limit winter logging and warmer and drier summers will reduce logging due to increased fire risk. Will disturbance by fire and insects become more prevalent leading to a greater amount of the harvest being salvaged wood (Volney and Hirsch 2005)? The magnitude of the impact and the manage-

ment response to the mountain pine beetle epidemic in British Columbia is an example of what the future might hold. How will these changes affect industry viability, particularly as there will be an increase in global wood supply (Sohngen and Sedjo 2005)?

Reforestation is based on the selection of species and provenances that are genetically adapted to the site (climate and soil). A changing climate means that the appropriate provenances or species for a site would change (Spittlehouse and Stewart 2003). Even if we had reasonable knowledge of the climate limits of species and provenances, the unknown spatial and temporal distribution of the future climate severely hampers our ability to respond. It would not be prudent to change the guidelines at present because the climate may not have changed sufficiently to allow acceptable regeneration of the planting stock. Furthermore, because the climate will likely continue to change over the life of the stand, which climate regime should the planting stock be selected to meet?

### Adapting to Climate Change in Forestry – Responses

Although we do not have a clear view of the future climate and forest, or of the vulnerability of species and society, it is critical to begin the process of developing adaptation strategies now. Adaptation requires a planned response well in advance of the impacts of climate change. Adaptation must address biophysical and socio-economic impacts and will require changes in forest policy to allow implementation. Risk analysis tools can be used in planning adaptive actions (Davidson *et al.* 2003, Ohlson *et al.* 2005). Dale *et al.* (2001) and Spittlehouse and Stewart (2003) indicate that adaptation requires that the forest community:

- Increase awareness and education within the community about adaptation to climate change.
- Establish objectives for the future forest under climate change. The debate will be about values, expectations and how society wishes to use its forest resources.
- Determine the vulnerability (sensitivity, adaptive capacity) of forest ecosystems, forest communities, and society.
- Develop present and future cost-effective adaptive actions. Current activities include those that facilitate future responses to reduce vulnerability. Adaptation options must include the ability to incorporate new knowledge about the future climate and forest vulnerability as they are developed.
- Monitor to determine the state of the forest and identify when critical thresholds are reached.
- Manage the forest to reduce vulnerability and speed recovery after disturbance.

Numerous adaptive actions have been proposed for forest management (Spittlehouse and Stewart (2003). They can be grouped into three categories: societal adaptation (e.g., forest policy to encourage adaptation, revision of conservation objectives, changes in expectations), adaptation of the forest (e.g., species selection, tree breeding, stand management, fire smart landscapes), and adaptation to the forest (e.g., change rotation age, use more salvage wood, modify wood processing technology).

Societal adaptation will be a major component of any forest management adaptation strategy. We will have to revise our demands on forest resources. Changes in forest productivity may be positive in some areas and activities such as

stand management and forest protection to address climate change impacts will provide benefits to communities (Johnson and Williams 2005, Volney and Hirsch 2005). Changes in wood quality and timber supply will occur globally and market impacts will not be uniformly distributed (Sohngen and Sedjo 2005). Non-timber forest products (NTFPs) such as mushrooms, berries and botanicals are an important part of the rural economy (Forest Practices Board 2004). Availability of some NTFPs may benefit from increase in disturbances such as fire whilst others will be reduced through changes in species distribution and growing conditions. There will also be changes in recreation opportunities. Warmer winters will shorten the winter recreational season while summer recreational season will increase, though increased fire risk may limit this increase.

In some areas, adaptation to reduce the vulnerability of resources such as water quality and quantity and biological conservation will become the highest priority. Forest harvesting and road building may have to mitigate the impacts of changes in the timing of peak flow and volume in streams on infrastructure, fish habitat, and potable water supplies (Mote *et al.* 2003). Warmer and drier summer conditions will increase the need to maintain cool stream temperatures by maintaining riparian cover for streams in harvested areas (Moore *et al.* 2005). Increased winter precipitation and the melting of permafrost in northern regions will require road maintenance to minimize road failure and sediment runoff (Spittlehouse and Stewart 2003). Adaptation of culverts, bridges and roads could be incorporated into the infrastructure replacement cycle.

As noted earlier, in much of Canada there is a large area of forested land that is not subject to harvesting or reforestation. Here it will be a case of society accepting how the forest adapts. Increased forest fire risk and limited financial resources may mean management must focus on the protection of areas with high economic or social value, while in other areas fire is allowed to run its course (Stocks *et al.* 1998, Parker *et al.* 2000, Volney and Hirsch 2005). Society will have to change its expectations for the use of forests and approaches to conservation. The “hands-off” approach to wilderness management may not be an appropriate response in parks and wilderness areas (Scott and Lemieux 2005). Rather than consider park ecosystems “frozen in time” it may be preferable to intervene by planting alternate species. Conserving biodiversity and maintaining connectivity in a varied dynamic landscape to aid vegetation and wildlife migration will be a high priority but connectivity also allows undesirable competitors and disturbance to move across the landscape. We may wish to identify areas for preservation where the future climate will become suitable for species whose current range is threatened by climate change.

Adapting the forest to the changing climate will be an appropriate action for reforestation after disturbances such as harvest or fire. The first steps involve determining the limits of transferability of species and provenances by defining their climatic envelopes and developing climate-based seed planting zones (Refeldt *et al.* 1999, Parker *et al.* 2000, Rainville and Beaulieu 2005, Wang *et al.* 2005). Provenance trials show how different species and provenances perform under a range of conditions. We could test Ledig and Kitzmiller’s (1992) suggestion of mixing a range of provenances at a site. Should

we choose species or provenances that can grow adequately over a wide climatic range rather than a provenance that grows better but over a narrower climatic range? There will likely be an increase in reforestation with hardwood species that can grow faster than conifers, reducing the rotation age and aiding adjustment to a continually changing climate. Changes in temperature and precipitation regimes will mean that we will have to revise where and how planting stock and site preparation techniques are used. Species have a wide range of occurrence and it would be prudent to initially target areas near the edge of a species range where the earliest impacts are likely to occur (Hogg and Bernier 2005). In some cases we may have to return to existing second growth stands where the current regeneration is unacceptable as a source for the future forest and replant with other species or genotypes (Woods *et al.* 2005). Reforestation and stand management will allow for the development of FireSmart landscapes that reduce the susceptibility to large fires (Volney and Hirsch 2005). Policies such as seed planning zones and other reforestation standards and guidelines designed for the current climate regime will need to be revised to account for climate change.

Options for adapting to changes in the Canadian timber supply for the next 50 to 100 years are different from those required for reforesting harvested land. They depend on how the existing forest responds to climate change. Options for adapting the forest include disease and insect control, stand management such as controlling undesirable species, partial cutting, sanitation thinning, fire protection and altering forest structure to reduce the extent of disturbance (Parker *et al.* 2000, Dale *et al.* 2001, Volney and Hirsch 2005). We need to develop growth and yield models that explicitly consider climate variability in predicting future yields (Hogg and Bernier 2005, Johnson and Williamson 2005). A shortening of the winter logging period through warming will require a revision of harvesting activities.

The forest industry will have to adapt pulp processing and manufactured wood products technology to changes in wood quality and quantity and increase diversity in processing technology and products. There will be pressure to make greater use of residues and salvage wood for wood products, bio-energy and other bio-products (Hanson and Edwards 2002, McKendry 2002, Lazar 2005). The forest carbon balance will have to be considered in forest management decisions and forests will be used to sequester carbon to offset anthropogenic emissions of carbon dioxide (Pollard 1991, Spittlehouse 2002). Including adaptation in forest planning is a risk management strategy and may aid in forest certification.

How and when does the forest community begin the process of adapting to climate change? A survey of forestry professionals (Williamson *et al.* 2005) indicated they recognise the need to be proactive on this issue. Asking the questions about how to adapt will help determine:

- Research and educational needs.
- Vulnerability of forest resources.
- Policies to facilitate implementation of adaptation in forest management.
- Monitoring systems to identify problems induced by climate change.

## Conclusions

Current forest utilization and preservation policies and activities are based on how forests developed under past climatic conditions. Policy-makers and forest managers must accept that a significant change in the climate will occur and that forests and forest-dependent communities face significant challenges. Planned adaptation in forest management will reduce the vulnerability of commercial tree species at selected sites. However, many forest species will have to adapt autonomously and society will have to adjust to the result. Until climate change has had sufficient impact to warrant intervention we are limited in what we can do at present on the ground, in the forest; but planning, monitoring, assessing forest vulnerability to climate change and developing adaptation strategies should start now. Sustainable forest management already embodies many of the biological, physical and societal actions that will be required to respond to the effects of climate change on forests. Including adaptation to climate change as part of forest planning does not necessarily require a large financial investment now with an unknown future payback time. Actions can be taken that are useful now, but could also reduce the risk of unacceptable losses in the future. Climate change adaptation strategies can be viewed as the risk management component of a sustainable forest management plan.

Most of Canada's forests are on crown land; therefore government agencies must take the lead on applying adaptation in forest management. The agencies are responsible for setting policies, developing management objectives and approving forest company stewardship plans. Governments set standards for species selection, seed transfer, stocking, and biodiversity and allocate land to parks and wilderness areas. They are also responsible for maintaining forest health and growth monitoring plots and provenance trials. Resulting forest policy changes and social considerations will need to take regional disparities of impacts into account. It is gratifying to see that many government agencies are taking seriously the threat of climate change to the forests and are starting the process of developing adaptation strategies.

## Acknowledgements

Support for this work is provided by the BC Ministry of Forests, Victoria, BC. and the Forest Investment Account – Forest Science Program. Discussions with numerous colleagues on impacts and adaptation are gratefully acknowledged.

## References

- Burton, I., S. Huq, B. Lim, O. Pilifosova and E.L. Schipper. 2002. From impacts assessment to adaptation priorities: the shaping of adaptation policy. *Climate Policy* 2: 145–159.
- Dale, V.H, L.A. Joyce, S. McNulty, R.P. Neilson, M.P. Ayres, M.D. Flannigan, P.J. Hanson, L.C. Irland, A.E. Lugo, C.J. Peterson, D. Simberloff, F.J. Swanson, B.J. Stocks, and B.M. Wotton. 2001. Climate change and forest disturbances. *BioScience* 51: 723–734.
- Davidson, D.J., T. Williamson and J. R. Parkins. 2003. Understanding climate change risk and vulnerability in northern forest-based communities. *Canadian J. Forest Research* 33: 2252–2261.
- Forest Practices Board. 2004. Integrating non-timber forest products into forest planning and practices in British Columbia. Special report FPB/SR/19, Forest Practices Board, Victoria, BC.

- Gray, P.A. 2005. Impacts of climate change on diversity in forested ecosystems: Some examples. *The Forestry Chronicle* 81(5): 655–661.
- Hanson, J. and S. Edwards. 2002. Towards a biobased economy: Issues and challenges paper. [www.pollutionprobe.org/Reports/Biobased.pdf](http://www.pollutionprobe.org/Reports/Biobased.pdf). Accessed on 15 June 2005.
- Hogg, E.H. and P.Y. Bernier. 2005. Climate change impacts on drought-prone forests in western Canada. *The Forestry Chronicle* 81(5): 675–682.
- Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden and D. Xiaosu. (eds.). 2001. *Climate change 2001: the scientific basis*. Intergovernmental Panel on Climate Change, Cambridge University Press, New York, NY.
- Johnson, M. and T.B. Williamson. 2005. Climate change implications for stand yields and soil expectation values: A Northern Saskatchewan case study. *The Forestry Chronicle* 81(5): 683–690.
- Kirschbaum, M.U.F. 2000. Forest growth and species distribution in a changing climate. *Tree Physiology* 20: 309–322.
- Lavender, D.P., R. Parish, C.M. Johnson, G. Montgomery, A. Vyse, R.A. Willis and D. Winston (eds.). 1990. *Regenerating British Columbia's Forests*. Univ. British Columbia Press, Vancouver, BC.
- Lazar, A.D. 2005. Editorial. *The Forestry Chronicle* 81(5): 631–633.
- Ledig, F.T. and J.H. Kitzmiller. 1992. Genetic strategies for reforestation in the face of global climate change. *Forest Ecology and Management* 50: 153–169.
- McKendry, P. 2002. Energy production from biomass (part 1): Overview of biomass. *Bioresource Technology* 83: 37–46.
- Moore, R.D., D.L. Spittlehouse and A. Story. 2005. Riparian microclimate and stream temperature response to forest harvesting — a review. *J. American Water Resources Assoc.* (in press).
- Mote, P.W. E.A. Parson, A.F. Hamlet, K.N. Ideker, W.S. Keeton, D.P. Lettenmaier, N.J. Mantua, E.L. Miles, D.W. Peterson, D.L. Peterson, R. Slaughter and A.K. Snover. 2003. Preparing for climate change: The water, salmon and forests of the Pacific Northwest. *Climatic Change* 61: 45–88.
- Ohlson, D.W., G.A. McKinnon and K.G. Hirsch. 2005. A structured decision-making approach to climate change adaptation in the forest sector. *The Forestry Chronicle* 81: 97–103.
- Parker, W.C., S.J. Colombo, M.L. Cherry, M.D. Flannigan, S. Greifenhagen, R.S. McAlpine, C. Papadopol and T. Scarr. 2000. Third millennium forestry: what climate change might mean to forests and forest management in Ontario. *The Forestry Chronicle* 76: 445–463.
- Pojar, J., K. Klinka and D.V. Meidinger. 1987. Biogeoclimatic ecosystem classification in British Columbia. *Forest Ecology and Management* 22: 119–154.
- Pollard, D.F.W. 1991. Forestry in British Columbia: planning for the future climate today. *The Forestry Chronicle* 67: 336–341.
- Rainville, A. and J. Beaulieu. 2005. Adaptation to climate change: can genetics be of help? *The Forestry Chronicle* 81(5): 704–709.
- Rehfeldt, G.E., C.C. Ying, D.L. Spittlehouse and D.A. Hamilton. 1999. Genetic responses to climate for *Pinus contorta*: niche breadth, climate change, and reforestation. *Ecological Monographs* 69: 375–407.
- Scott, D. and C. Lemieux. 2005. Climate change and protected area policy and planning in Canada. *The Forestry Chronicle* 81(5): 696–703.
- Smit, B. and O. Pilifosova. 2002. From adaptation to adaptive capacity and vulnerability reduction. In S. Huq, J. Smith, R.T.J. Klein (eds.). *Enhancing the Capacity of Developing Countries to Adapt to Climate Change*. Chapter 2. pp. 1–19. Imperial College Press, London.
- Sohnngen, B. and R. Sedjo. 2005. Impacts of climate change on forest product markets: Implications for North American producers. *The Forestry Chronicle* 81(5): 669–674.
- Spittlehouse, D.L. 2002. Carbon credits. *Canadian Silviculture* Fall: 10–13.
- Spittlehouse, D.L. 2003. Water availability, climate change and the growth of Douglas-fir in the Georgia Basin. *Canadian Water Resources J.* 28: 673–688.
- Spittlehouse, D.L. and R.B. Stewart. 2003. Adapting to climate change in forest management. <http://www.forrex.org/jem/2003/vol4/no1/art1.pdf>. Printed version, *J. Ecosystems and Management* (2004) 4(1): 7–17.
- Standing Senate Committee on Agriculture and Forestry. 2003. *Climate change: we are at risk*. Final Report, Government of Canada, Ottawa, ON.
- Stewart, R.B., E. Wheaton and D.L. Spittlehouse. 1998. Climate change: implications for the boreal forest. In A.H. Legge and L.L. Jones (eds.). *Emerging air issues for the 21st century: the need for multidisciplinary management*. pp. 86–101. Air and Waste Management Assoc., Pittsburgh, PA.
- Stocks, B.J., M.A. Fosberg, T.J. Lynham, L. Mearns, B.M. Wotton, Q. Yang, J-Z. Jin, K. Lawrence, G.R. Hartley, J.A. Mason and D.W. McKenney. 1998. Climate change and forest fire potential in Russian and Canadian boreal forests. *Climatic Change* 38: 1–13.
- Volney, W.J.A. and K.G. Hirsch. 2005. Disturbing forest disturbances. *The Forestry Chronicle* 81(5): 662–668.
- Wang, T., A. Hamann, D.L. Spittlehouse and S.N. Aitken. 2005. Development of scale-free climate data for western Canada for use in resource management. *International J. Climatology* (in press).
- Williamson, T.B., J.R. Parkins and B.L. McFarlane. 2005. Perceptions of climate change risk to forest ecosystems and forest-based communities. *The Forestry Chronicle* 81(5): 710–716.
- Woods, A.J., K.D. Coates and A. Hamann. 2005. Is an unprecedented Dothistroma needle blight epidemic related to climate change? *Bioscience* 9:761–769.