Perspectives

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Adaptation to climate change in forest management

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Abstract

Adaptation in forestry is sustainable forest management that includes a climate change focus. Climate change over the next 100 years is expected to have significant impacts on forest ecosystems. The forestry community needs to evaluate the long-term effects of climate change on forests and determine what the community might do now and in the future to respond to this threat. Management can influence the timing and direction of forest adaptation at selected locations, but in many situations society will have to adjust to however forests adapt. Adapting to climate change in the face of the uncertain timing of impacts means we must have a suite of readily available options. A high priority will be coping with and adapting to forest disturbance while maintaining the genetic diversity and resilience of forest ecosystems. A framework for facilitating adaptation in forestry is discussed and a review of adaptive actions presented.

KEYWORDS: *climate change, sustainable forest management, adaptation.*

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Introduction

The Third Assessment Report of the Intergovernmental Panel on Climate Change concluded that the Earth is warming, and that some of this warming is due to the burning of fossil fuels and deforestation (Houghton *et al.* 2001). By the end of the 21st 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. An increase in winter precipitation and a decrease in summer precipitation may also occur. These changes would significantly affect human society and ecosystems (McCarthy *et al.* 2001). The interim report on climate change from Canada's Standing Senate Committee on Agriculture and Forestry (2003) emphasizes the vulnerability of Canada's natural resource industries to climate change and the need for the forestry community to be proactive in adapting to climate change.

Adaptation to climate changes refers to adjustments in ecological, social, and economic systems in response to the effects of changes in climate.

Adaptation moderates vulnerability to climate change. Although forest ecosystems will adapt autonomously, their importance to society means that we may wish to influence the direction and timing of this adaptation at some locations. In other cases, society will have to adjust to whatever change brings. Adaptation is not something to be applied only in the future; actions are needed now in anticipation of future conditions. Furthermore, Stewart *et al.* (1998) and Walther *et al.* (2002) described responses in forest ecosystems to current climate change that require adaptive actions now.

The objective of this paper is to encourage the forestry community to evaluate the long-term impacts of climate change and determine what the community might do now and in the future to respond to this threat. Sustainable forest management embodies many of the activities that will be required to respond to the effects of climate change on forests. Holling (2001) notes that an adaptive capability is a necessary component of sustainability. Including adaptation to climate change as part of forest planning does not necessarily require a large financial investment with an unknown future payback time. We present a framework for adaptation analysis in forestry, review the literature on adaptation in forestry, identify some knowledge gaps, and suggest a way forward.

Adaptation in Forestry

The life cycles of forests range from decades to centuries. Decisions made today are based on the assumption that the climate will remain relatively stable throughout a forest's life. This may have worked well in the past, but future climate change challenges this assumption. Predictions of biological changes over the next century range from large-scale biome shifts (Aber *et al.* 2001; Scott *et al.* 2002) to relatively less extensive disruptions in forest growth (Loehle 2000). Responses will be at the species level with the movement of species ranges northward and up in elevation, and the occurrence of new assemblages of species in space and time (Hebda 1997; Kirschbaum 2000; Hansen *et al.* 2001). In some areas, responses will be mediated by physical factors, such as nutrient availability, soil depth, and permafrost (Stewart *et al.* 1998). Most of the climate change research in forestry has focused on forecasting impacts. However, this work faces significant challenges because of our limited knowledge about the vulnerability of ecosystems and species, and the poor spatial and temporal resolution of the future climate. Even without a clear view of the future climate and forest, it is possible to develop adaptation strategies now. And we need to start now because adaptation to climate change in forest management requires a planned response well in advance of the impacts of climate change.

Adaptation to climate changes refers to adjustments in ecological, social, and economic systems in response to the effects of changes in climate (Smit *et al.* 2000; Smit and Pilifosova 2001). 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). Indeed, some people may view responding as a greater risk than doing nothing, or that adaptation is not a feasible option. An effective adaptation policy must be responsive to a wide variety of economic, social, political, and environmental circumstances. As discussed by Spittlehouse (1997), Dale *et al.* (2001), Holling (2001), and Smit and Pilifosova (2001), adaptation requires us to:

- Establish objectives for the future forest under climate change.
- Increase awareness and education within the forestry community about adaptation to climate change.
- Determine the vulnerability of forest ecosystems, forest communities, and society.
- Develop present and future cost-effective adaptive actions.
- Manage the forest to reduce vulnerability and enhance recovery.
- Monitor to determine the state of the forest and identify when critical thresholds are reached.
- Manage to reduce the impact when it occurs, speed recovery, and reduce vulnerability to further climate change.

Forest managers have many options for mitigating the effects of climate change and adapting to that change (Duinker 1990; Wall 1992; Spittlehouse 1997; Stewart *et al.* 1998; Papadopol 2000; Parker *et al.* 2000; Dale *et al.* 2001). A summary of adaptive actions suggested by these and other authors follows the References section. Detailed discussions of the effects of climate change are available in many of the papers cited in the reference list. We focus here on a framework for planning adaptive actions.

The framework consists of four steps (see Table 1). The first is defining the issue. The second involves the assessment of the vulnerability to change (sensitivity, adaptive capacity) of the forest, forest communities, and society. This allows the development of adaptive actions

TABLE 1. Three examples of applying the framework for adaptation in forestry. A summary of adaptive actions for other issues and areas of forest management follows the References section.

Step 1 Issue	**Effects of warmer annual and drier summer conditions on tree growth in southern British Columbia**	**Effects of climate change on managing parks and wilderness areas**	**Effects of warmer winters and increased winter precipitation on managing forest operations**
Step 2 Vulnerability	• Reduced growth rates • Increased disturbance through fire and insects • Changes in wood quality and quantity • Reduced regeneration success • Increased competition from exotics (vegetation, insects, and diseases)	• Changed climate means that protected values no longer exist in the area • Changes in wildlife habitat and suitability for non-timber forest products	• Reduced access for winter logging • Increased erosion from roads and landslides • Changes in timing and size of peak flows in streams
Step 3 Adaptation: Current actions	• Identify more suitable genotypes through provenance trials • Develop technology to use altered wood quality and size • Include climate variables in growth and yield models • Develop "fire-smart" landscapes	• Engage public in a dialogue on values and management under a changing climate • Conserve biodiversity • Maintain connectivity in a varied, dynamic landscape • Monitor to determine when and what changes are occurring	• Develop alternate harvesting systems • Include climate change considerations when planning maintenance and replacement of infrastructure
Step 4 Adaptation: Future actions	• Modify seed transfer zones • Plant alternate genotype or new species • Sanitation thinning • Increase amount of salvage logging • Change rotation length • Plan landscapes to minimize spread of insects and diseases	• Actively manage to adjust to species suitable to the new climate • Accept whatever change brings	• Implement alternate harvesting practices • Upgrade infrastructure as part of the replacement cycle • Maintain and rehabilitate roads to reduce sedimentation

to be taken now (step 3) and those required for the future (step 4) as change occurs. Current activities include those that facilitate future responses to reduce vulnerability. Actions under steps 3 and 4 need to be flexible enough to incorporate new knowledge of the future climate and forest vulnerability. Three examples that use this framework are presented in Table 1. The suggestions for action are a small subset of possible responses. Developing a dialogue within the forest management community will increase the range of options and aid evaluation of the cost-effectiveness of these actions.

Climate change adaptation strategies can be viewed as a risk management component of sustainable forest management plans. The precautionary principle advocates taking steps by implementing strategies that are useful now, but would also reduce the risk of unacceptable losses in the future. Many actions required to adapt to climate change benefit the present as well as the future (e.g., provenance trials). Forest policy needs to be assessed to ensure it encourages adaptation (Duniker 1990; Parker *et al.* 2000; Burton *et al.* 2002).

Climate change adaptation strategies can be viewed as a risk management component of sustainable forest management plans.

Including adaptation in forest management requires a landscape-level view of the forest and integration across all parts of the forest sector. To maintain sustainability of timber and non-timber resources and to assess economic implications, spatial planning tools are necessary to design and evaluate options. Although making these tools work effectively still poses challenges (Loehle *et al.* 2002), they provide us with an opportunity to evaluate the effects of climate change on future forests and test adaptive responses (Donnelly 2001; Spittlehouse 2001; Lindner *et al.* 2002). To effectively use these tools, we need to identify and fill the knowledge gaps on the vulnerability of species and genotypes. Adaptive actions, if applied unwisely or without a good understanding of the biophysical implications, could exacerbate the effects of climate change (Duinker 1990).

Conclusions

Current forest utilization and preservation is based on how forests developed under past climatic conditions. Policy-makers and forest managers must accept that climate change is probable and that forests and forest communities face significant impacts. Sustainable forest management is already based on many of the measures to adapt to climate change presented following the References section. Planned adaptation will reduce vulnerability for commercial tree species at selected sites. However, many forest species will have to adapt autonomously and society will have to adjust to the result. Adaptation requires planning for change so that a suite of options is available whenever needed. To facilitate this, a number of management questions must be addressed:

- What research must be done now to aid development of strategies for adapting to climate change?
- What are the educational needs of the forestry community to increase awareness of climate change, and to facilitate adaptation?
- What do we need to know to evaluate forest response to climate change?
- What forest management actions could be taken now that do not compromise future responses?
- What barriers exist to implementing adaptation in forest management?
- What forest policies need to be in place to facilitate adaptation?
- Are current monitoring systems adequate to spot problems induced by climate change soon enough to allow implementation of an acceptable response?
- Which forest ecosystems and species will have to adapt autonomously and where can we intervene to assist adaptation?

In conclusion, a strategy to adapt to climate change should be viewed as part of the risk management component of a sustainable forest management plan.

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A Summary of Adaptive Actions in Forestry

This summary of adaptations to climate change for forest management is broken down into the following topics: gene management, forest protection, forest regeneration, silvicultural management, forest operations, non-timber resources, and park and wilderness area management. Potential management issues are presented at the beginning of each of topic.

Gene Management

Seed transfer zones are based on the assumption of optimum climatic limits to species and provenances. A changing climate means that the geographic extent of these zones will change. In general, ranges are expected to move upward in elevation and northward in latitude in the Northern Hemisphere and new assemblages of species will occur in space and time (Kirschbaum 2000; Hansen *et al.* 2001). Consequently, activities required for adapting to these changes and maintaining genetic diversity and resilience in the commercial forest include:

- Determining the responses of species and genotypes to climate and the limits of their transferability, and developing climate-based seed zones that will change over time (Schmidtling 1994; Rehfeldt *et al.* 1999; Parker *et al.* 2000). Provenances need to be tested at the limit of their ecological range; it is important to understand the physiological basis for responses (Tyree 2003).
- Breeding for pest resistance and for a wider tolerance to a range of climate stresses and extremes in specific genotypes (Namkoong 1984; Wang *et al.* 1995).
- Re-evaluating seed orchard locations. A changing climate may mean that existing seed orchards would eventually be in climatic regimes unsuitable for seed production of some species. If orchard seed supplies are reduced, an increasing reliance will be placed on the use of wild-stand seed.
- Planting a mixture of provenances at a site (Ledig and Kitzmiller 1992).
- Re-evaluating conservation and recovery programs. Rare and endangered plant species usually have specialized environmental requirements and low genetic diversity (Peters 1990; Hansen *et al.* 2001). In many cases, the long-term preservation of some rare species may only be possible in artificial reserves or arboreta, rather than in natural environments (Parker *et al.* 2000).

Forest Protection

Rapid changes in forest age class distribution and landscape patterns could be induced through altered timing and increases in the frequency and intensity of disturbances, such as fire (Stocks *et al.*1998; Wheaton 2001), wind (Petersen 2000), ice storms (Irland 2000), and pests (Sieben *et al.* 1997; Volney and Fleming 2000). Interactions may also occur between insect disturbance, a warmer and drier climate, and fire (Fleming *et al.* 2002). Adaptive actions to deal with potential changes in forest fire regimes include:

- Focusing on the protection of areas with high economic or social value, while in other areas allowing fire to run its course (Stocks *et al.* 1998; Parker *et al.* 2000). Any future increases in wildfire are expected to overwhelm the ability of fire management agencies to respond to all occurrences.
- Altering forest structure (e.g., tree spacing and density, standing dead trees, or coarse woody debris on the forest floor) to reduce the risk and extent of disturbance (Dale *et al.* 2001); increasing use of prescribed burning to minimize fuel loading (Wheaton 2001).
- Developing "fire-smart" landscapes by using harvesting, regeneration, and stand-tending activities that manage fuels to control the spread of wildfire (Hirsch and Kafka 2001; Climate Change Impacts and Adaptation Directorate 2002). For example, stands of aspen, which is a fire-resistant species, could be planted amidst the more flammable conifers in the boreal forest to reduce the vulnerability to large fires. This is an example of an adaptive action that needs to be started now to be effective decades into the future.
- Enhancing forest recovery after fire disturbances (Wheaton 2001).

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Future climate change may increase the thermal and moisture stress on the existing forest. Stressed and aging tree populations will be more vulnerable to insects and disease. Adaptive actions for protection against insects and disease include:

- Partial cutting or thinning to increase stand vigour and lower the susceptibility to attack (Wargo and Harrington 1991; Gottschalk 1995).
- Reducing disease losses through sanitation cuts that remove infected trees. Care will be required because these practices can increase vulnerability to other pests (Smith *et al.*1997).
- Shortening the rotation length to decrease the period of stand vulnerability to damaging insects and diseases (Gottschalk 1995) and facilitating change to more suitable species (Lindner *et al.* 2000).
- Using insecticides and fungicides in situations where silvicultural activities for insect pest management are ineffective or inappropriate (Parker *et al.* 2000).
- Using genotypes bred for improved resistance to pests (Namkoong 1984).

Forest Regeneration

Existing forests are quite resistant to climate variability (Noss 2001)—it is the regeneration phase that will initially be susceptible to the changed climate. Forest disturbances can be viewed as a way to speed adjustment to climate change by facilitating the spread or planting of genotypes or species more suitable to the new climate. However, non-commercial tree species and understorey vegetation will have to migrate without intentional intervention. Adaptive actions include:

- Identifying drought-tolerant genotypes (Farnum 1992).
- Assisting the migration of commercial tree species from their present to future ranges through artificial regeneration (Parker *et al.* 2000). The northward movement of certain species will, in some instances, be hindered by the lack of suitable soil conditions, such as nutrients, soil depth, and mycorrhizae.
- Planting provenances that grow adequately under a wide range of conditions and (or) planting stock from a range of provenances at a site (Ledig and Kitzmiller 1992).
- Controlling undesirable plant species, which become more competitive in a changed climate, through vegetation management treatments (Parker *et al.* 2000).

Silvicultural Management

Future climate change may increase the productivity of northern forests, at least in the near term (Cohen and Miller 2001). Nutrient availability and acclimation by trees are likely to limit the potential for increased growth due to the higher concentration of atmospheric carbon dioxide. Warmer sites may see increased respiration, offsetting any gains. At the drier end of forested zones, grassland encroachment can be expected (Hebda 1997). Consequently, maintaining forest ecosystems in the face of progressive climate change will require silvicultural systems to manage declining and disturbed stands. Adaptive actions to address this include:

- Pre-commercially thinning or selectively removing suppressed, damaged, or poor quality individuals to increase light, water, and nutrient availability to the remaining trees (Smith *et al.*1997; Papadopol 2000).
- Reducing vulnerability to future disturbances by managing tree density, species composition, forest structure (e.g., underplanting; planting late-successional species), and location and timing of management activities (Dale *et al.* 2001).
- Underplanting with other species or genotypes where the current advanced regeneration is unacceptable as a source for the future forest.
- Reducing the rotation age followed by planting to speed the establishment of better-adapted forest types (Lindner *et al.* 2000; Parker *et al.* 2000).

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Forest Operations

Biological and climate changes have implications for forest operations. Increased winter precipitation could affect water management in forests. An increased risk of sediment transport to streams could degrade water quality and fish spawning habitat. Warmer winters will reduce the opportunities for winter logging in areas where the frozen surfaces of forest roads and ice bridges are essential for site access and where a snow pack is necessary to protect the land during harvesting (Pollard 1991; Donnelly 2001). Harvesting restrictions could be imposed due to the increased risk of landslides under heavy rainfall. Declining stand quality and increased disturbance will affect wood quality and timber supply locally and globally (Solomon *et al.* 1995; Perez-Garcia *et al.* 2002). Forest policies addressing climate change will need to account for regional and market impacts that are not uniformly distributed (Perez-Garcia *et al.* 2002). Previous sections outlined some adaptive actions for forest operations. Others include:

- Increasing the amount of timber from salvage logging of fire- or insect-disturbed stands. There are implications here for revenue generation from the forest, fibre quality, and size of lumber.
- Maintaining, decommissioning, and rehabilitating roads to minimize sediment runoff due to increased precipitation and the melting of permafrost in northern regions. Advanced planning for climate change allows for infrastructure replacement as part of the normal replacement cycle.
- Mitigating the impacts on infrastructure, fish, and potable water supplies, of changes in the timing of peak flow and volume in streams resulting from increased winter precipitation and earlier snow melt.
- Including adaptation planning in forest certification as part of a risk management strategy.
- Mitigating climate change through forest carbon management (Parker *et al.* 2000; Spittlehouse 2002; White and Kurz 2003); evaluating the risk of climate change to carbon stocks (Kurz and Apps 1996; Fleming *et al.* 2002).
- Increasing the use of forests for biomass energy.
- Developing policies to facilitate the creation and implementation of adaptive management responses to climate change (Duinker 1990; Spittlehouse 1997; Parker *et al.* 2000; Burton *et al.* 2002).

Non-timber Resources

Climate change will affect habitat quality and availability for wildlife and influence predator/prey synchrony (Harding and McCullum 1997; Stenseth *et al.* 2002). Species ranges are expected to shift upward in elevation and northward in latitude in the Northern Hemisphere (Kirschbaum 2000). Changes in resource availability will have a large impact on communities where lifestyle is strongly tied to these resources for food and culture. For example, warmer summers and increased winter snow are predicted to result in a decline in the Porcupine caribou herd, a resource critical to the well-being of the people of Old Crow, Northwest Territories (Eamer *et al.* 1997). In the case of most non-timber resources, management will likely be limited to minimizing impediments to autonomous adaptation through:

- Minimizing fragmentation of habitat and maintaining connectivity (Peters 1990; Noss 2001).
- Maintaining representative forest types across environmental gradients and protecting primary forests (Holling 2001; Noss 2001; Carey 2003). Established forests are often able to survive extensive periods of unfavourable climates and this inertia could extend the time period over which adaptation could take place.
- Maintaining diversity of functional groups as well as species within groups (Holling 2001; Noss 2001).

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Park and Wilderness Area Management

Traditionally, the management of these areas tends to follow a hands-off approach (i.e., "let nature take its course"). This may not be feasible under a changed climate, given that the values and attributes the park or wilderness areas were designed to protect may no longer exist within the protected area (Halpin 1997; Suffling and Scott 2002). The risk of loss of specific types of ecosystems, such as wetlands (Cohen and Miller 2001) and the island forests of the Great Plains (Henderson *et al.* 2002) is also possible. These changes will challenge agencies such as Parks Canada, whose mandate is to protect representative areas of Canadian significance for all time (Scott *et al.* 2002). Adaptive actions include:

- Managing to delay, ameliorate, and direct change. This would include a number of the actions outlined previously, require extensive stakeholder input and a reassessment of our current view of conservation and our approach to it (Lopoukhine 1990; Henderson *et al.* 2002; Suffling and Scott 2002).
- Identifying and planting alternate tree species (Suffling and Scott 2002; Henderson *et al.* 2002).
- Conserving biodiversity and maintaining connectivity in a varied, dynamic landscape to aid vegetation and wildlife migration as the climate changes (Noss 2001; Carey 2003).