# Impacts and Adaptation for Climate Change in Urban Forests

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## ABSTRACT

The likelihood of climate change in Canada is now accepted by the majority of the scientific community. Climate change is expected to bring warmer, wetter winters and warmer drier summers, and rates of fire and insect disturbance are expected to increase. In addition, these effects will interact with existing urban stresses such as air pollution, soil compaction and heat island effects. Since it is unlikely that these effects can be fully prevented, it is essential that adaptive strategies be identified early so they can be implemented by urban forest managers before these impacts are felt. Managing for tree health will become increasingly important, and selection for tree species and varieties that are drought, heat and insect resistant will become a necessity. Managing fire in the wildland-urban interface will become critical in the coming decades, with fire-smart activities playing an increasing role in community planning. Climate change will present both threats and opportunities, and it is not too early to begin planning for both.

## INTRODUCTION

Climate change is now an accepted reality among the scientific community (Orestes 2004). Recent reviews of the scientific literature leave little doubt that the climate is changing now and will continue to change in the future (e.g. McCarthy et al. 2001, ACIA 2004). Changes in temperature, precipitation, frost-free days and other environmental factors will affect the ways in which urban trees are established and grow. In addition, these factors will interact with human activities in ways that are likely to add additional stress to urban forests. The objective of this paper is to review briefly some of the expected changes in climate, suggest how these changes may affect urban trees, and indicate how these factors might interact with other human influences. Finally, I present some ways in which urban forest managers can start to think about how urban forest management might adapt to climate change.

## CLIMATE AND CLIMATE CHANGE

Climate change will vary in extent and severity across Canada, and it is difficult to generalize about its effects (Cohen and Miller 2001). However, some general patterns are beginning to emerge. The following are general conclusions from the Intergovernmental Panel on Climate Change Third Assessment Report (McCarthy et al. 2001). Global climate models (GCMs) are large computer models of the earth's atmosphere, oceans and vegetation. These models increasingly agree that winter and spring temperatures will be higher with higher amounts of precipitation (Figure 1). Nighttime temperatures will increase more rapidly than daytime temperatures, causing a decrease in the diurnal temperature range. Summers temperatures are likely to be somewhat higher on average, but will probably not increase as much as those in winter. Summer precipitation may not change very much, but higher temperatures will result in greater evapotranspiration, causing soil moisture levels to decline. In addition to these long-term trends, climatologists suggest that extreme events will increase in frequency. These include, for example, the occurrence of very hot days, increased number of winter storms and high rainfall events. Finally, higher levels of atmospheric $CO_2$ will affect photosynthesis, with associated impacts on urban tree growth as moderated by the influence of the other factors described above. The following sections describe these impacts in greater detail.

## TEMPERATURE

Higher temperatures generally result in increased rates of photosynthesis, thereby increasing tree growth. However, higher rates of photosynthesis can only be supported if other resources are sufficient, e.g. water and nutrients, especially nitrogen. In addition, carbon losses due to respiration may also increase with temperature, so it is ultimately a matter of whether increased photosynthesis will offset increased losses due to respiration. See Roy et al. (2001) for a detailed discussion of the relationships among photosynthesis, respiration and environmental factors.

Higher temperatures when water is not available will result in increased heat and moisture stress, and higher temperatures in spring and fall will result in a longer growing season. Zhou et al. (2001) recently documented an increase in growing season length of 12 and 18 days for forests in North America and Northern Eurasia, respectively. Longer growing season will probably result in earlier leaf flush and other phenological changes. For example, Beaubien and Freeland (2000) found that the date of first flowering in aspen advanced by 26 days over the period 1900-1997 in Edmonton, Alberta (Figure 2). Higher temperatures in winter may also increase the likelihood of winter kill, in which trees begin to circulate water and nutrients in their vascular tissue as the temperatures warm. If this is followed by rapid cooling (e.g. Chinook conditions in southern Alberta), tissues will freeze and the trees will sustain injury or death. Finally, warmer temperatures will provide less control on insect populations, may of which are kept at low levels by cold winter temperatures (Volney and Fleming 2000). Insect - climate change interactions are treated in greater detail below.

Higher air temperatures will also generally lead to higher soil temperatures. This may allow root function (e.g. water uptake) to begin earlier in the spring, but will depend on timing of snowmelt and permeability of soil. It may also increase levels of available soil nutrients but this will depend on other soil factors such as soil compaction and soil organic matter.

In general, trees will grow faster under higher temperatures if other resources are not limiting. However, urban trees are often under stress caused by inadequate soil moisture due to soil compaction and hardened surfaces. These conditions also lead to lack of nutrient availability in some case. Therefore, higher temperatures will likely lead to increased stress levels for trees in urban settings, and urban heat island effects are likely to magnify these stresses (Arnfield 2003).

## PRECIPITATION

Precipitation is not well modeled by GCMs as compared to temperature (REF). Most model results indicate that precipitation is likely to increase in the winter and spring, and remain near current levels in summer (REF). However, there is regional variation in Canada, with eastern areas generally wetter than western (as with the current climate). If winter precipitation increases, urban trees are at greater risk from physical damage due to increased snow and ice loading. Nordin (1998) provides a detailed inventory of tree damage resulting from the 1998 Ontario-Quebec ice storm; see also Sisinni et al. (1995) for impacts of ice storms to street trees in Rochester, NY. Even though precipitation will likely remain near current levels in summer, higher temperatures will result in greater levels of evaporation and transpiration, meaning that soil moisture levels are likely to be lower (Johnston 2001). This will cause increased levels of moisture stress, and is likely to be exacerbated by existing problems in urban landscapes, i.e. soil compaction and hardened surfaces. Increased extreme rainfall events will likely cause more frequent flooding, which can cause injury or death to tree root systems if waterlogged soils persist for several days.

## CARBON DIOXIDE

Atmospheric levels of $CO_2$ have increased from about 280 parts per million (ppm) in pre-industrial times to about 375 ppm today (CDIAC 2004). Laboratory studies have shown that higher levels of $CO_2$ result in increased rates of photosynthesis and therefore greater plant growth rates (REF). Studies of loblolly pine grown in natural stands and exposed to high levels of $CO_2$ also show increases in growth in the first few years of exposure. However, in 3-5 years growth returns to previous levels, in a process called acclimation (Oren et al. 2001). The response was also dependant on adequate nutrients (especially nitrogen) and water. Aspen exposed to $CO_2$ and ozone (a common urban air pollutant) showed a growth increase from $CO_2$ alone and a decrease in growth from ozone alone, but no change when exposed to both. Apparently the benefits from CO2 were cancelled by the negative effects of ozone (Isebrands et al. 2001). This has important implications for urban trees growing in areas where ozone is an important air pollutant, i.e. the $CO_2$ fertilization effect may not provide the benefits many expect.

Plants take up $CO_2$ through stomata in the leaves, but lose water at the same time through transpiration. Under increased $CO_2$, less water is lost for a given unit of $CO_2$ uptake (known as water-use efficiency or WUE). This increase in WUE could be particularly important on water-limited sites, such that growth might continue where it would be severely limited under current $CO_2$ levels. However, it is difficult to predict the importance of this mechanism to growth given the other environmental factors at work as described above (see Roy et al. 2001 for further information on transpiration and its response to environmental factors). The evidence so far suggests that increased $CO_2$ may result in increases in tree growth if other factors are not limiting, and that this effect may be temporary for some species.

## INSECTS AND CLIMATE CHANGE

Insects have the potential to be a major problem for urban forests under climate change. Higher temperatures and longer growing seasons will allow populations to build up to higher levels due to higher levels of reproduction and/or reduced mortality. A well-known example of this is the mountain pine beetle in BC. This range of this species is generally limited by the occurrence of -40 C temperatures (Carroll et al. 2003). As the frequency of these temperatures change, the range of this species is expected to increase. In addition, exotic insect species may be able to persist and flourish under warmer temperatures where they might previously have been controlled by colder temperatures. The introduction and establishment of such exotic species as the Asian longhorned beetle and the emerald ash borer may be easier and more likely under warmer climatic conditions. Drought has been shown to increase insect feeding activity due to increased concentrations if carbohydrates in foliage under dry conditions (Mattson and Haack 1987).

## FIRE AND CLIMATE CHANGE

Warmer and dryer summers are likely to bring longer fire seasons and larger, more severe and frequent fires under future climate (Figure 3; Flannigan et al 2001, Flannigan et al. 2004). Recent experience in Kelowna in August 2003 underscores the importance of forest fires to managing forests the wildland-urban interface to reduce fire hazard. It is essential that communities with significant exposure to forest fire risk adopt FIRESMART techniques for reducing fuel loadings, reducing flammability of structures, eliminating sources of ignition (e.g. chimneys) and developing community disaster preparedness plans. The Alberta Sustainable Resource Development Department has produced a guide for homeowners on how to carry out a comprehensive FIRESMART inventory of their home and surrounding land (Figure 4, ASRD 2003). The guide also provides good advice on what steps to take to reduce fuels and fireproof structures.

## OTHER INTERACTIONS

Urban trees under stress from future drought and higher temperatures will be increasingly vulnerable to existing urban stressors, e.g. air pollution, soil compaction, impervious surfaces etc. At the same time, ecological services provided by trees will become more valuable under future climate: shading and space cooling, soil aeration and stabilization, uptake of storm water, etc. Urban forests will play a major role in our ability to cope with future climate change.

In summary, tree growth may be enhanced on sites with adequate water and nutrients, but will probably decline on sites that are already marginal. Impacts from other urban stressors will likely increase.

## ADAPTING TO CLIMATE CHANGE

Urban forest managers need to start thinking about their ability to cope with the impacts described above. The most important question to start with is: What is the current degree of vulnerability to climate-related events today? Regardless of how climate changes in the future, doing a better job of coping with current climate will pay dividends immediately, as well as preparing for future change. Managers also need to assess their adaptive capacity: once adaptation options are identified, is it possible to actually implement these options? Are budgets sufficient? Are municipal and provincial policies sufficient and appropriate? Have the forest managers consulted with other departments so adaptive responses are consistent across departments? These questions will determine whether adaptation is possible and whether is likely to be carried out. It is also important to recognize that trees grow slowly, and that decisions taken now about forest management will play out over several decades. Climate and climate change needs to become a part of decision-making today. Maintaining a flexible and resilient urban forest management system is the best defence, since specific climate change impacts cannot be predicted.

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Appendix

Figure 1. Expected Annual Mean Temperature Change for the 2050s as Predicted by the Canadian Global Circulation Model Version 2 (courtesy Canadian Climate Impacts Scenarios website: http://www.cics.uvic.ca/scenarios/index.cgi).

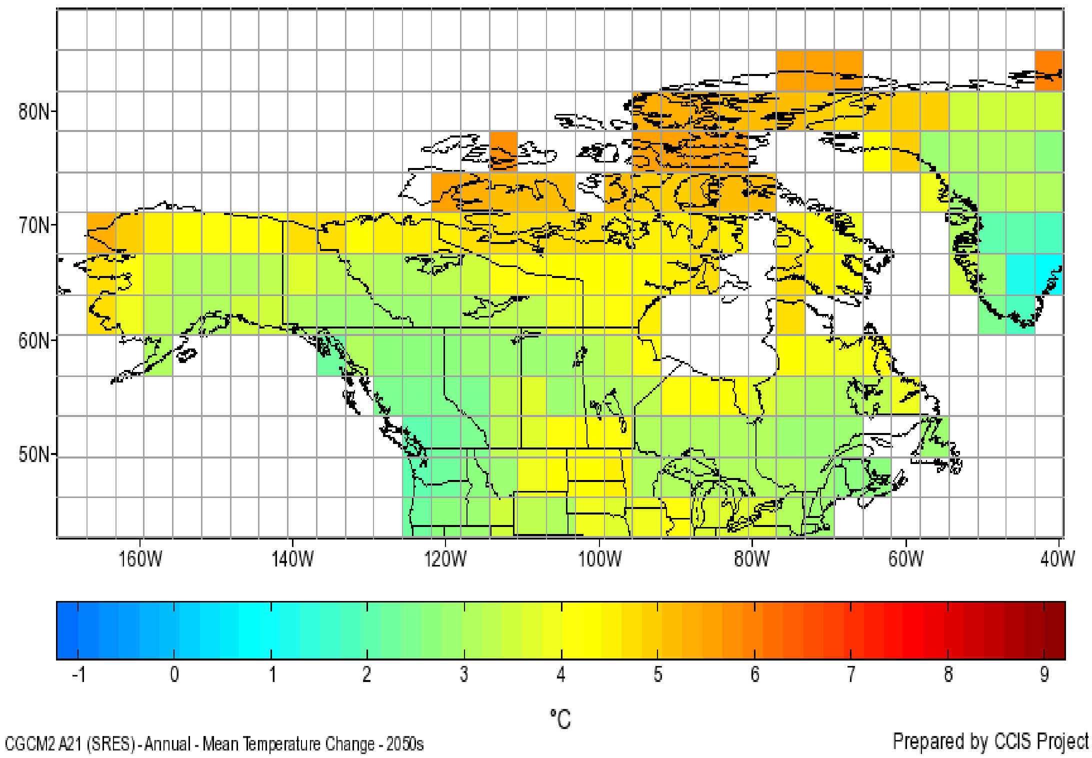

Figure 2. Earlier dates of first flowering in relation to temperature for poplar, Saskatoon berry and choke cherry at Edmonton, Alberta for the period 1936-1998. From Beaubien and Freeland (2000).

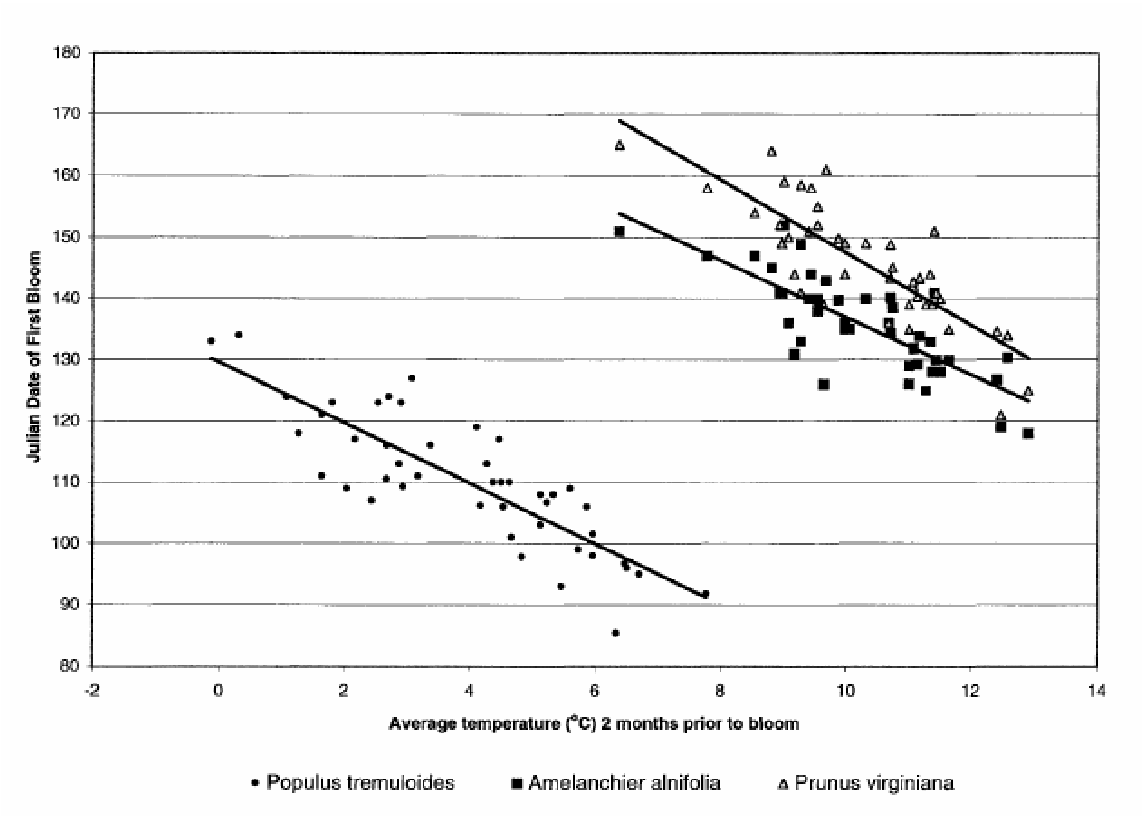

Figure 3. Area burned increase by Ecoregion in Canada. Values are ratio of $1XCO_2/3XCO_2$. From Flannigan et al. 2004.

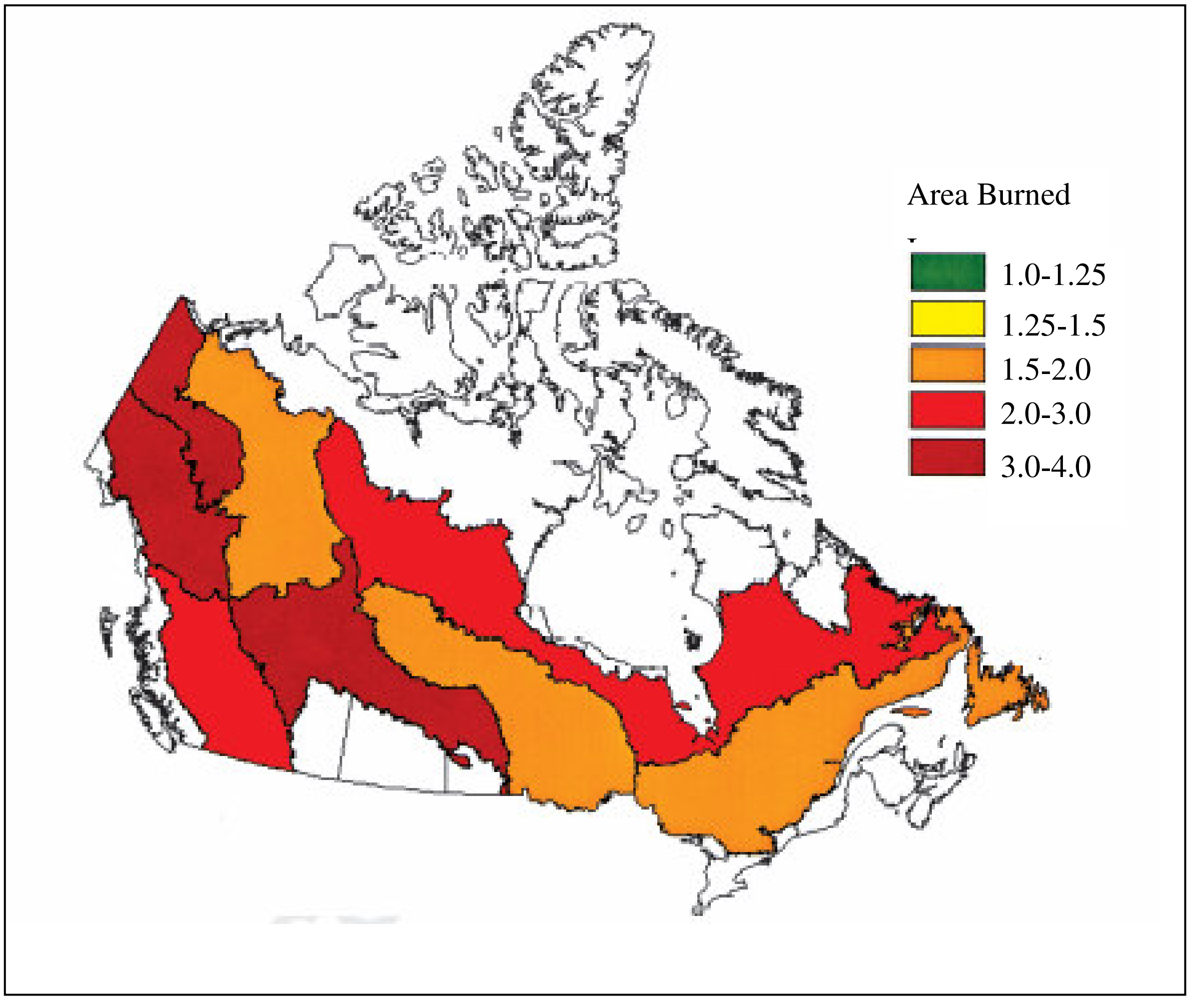

Figure 4. FIRESMART planning for rural residences. FIRESMART Planning Manual, Alberta Sustainable Resource Development.