Climate change and forest seed zones: Past trends, future prospects and challenges to ponder

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ABSTRACT

Canada regenerates more than 400 000 ha of forest land annually through planting and seeding operations. Much of the stock for this effort is selected to be climatically suited to the planting site—a match that is often facilitated through the development of seed zones. However, if climate change proceeds as predicted, stock that is well matched under current climate will be growing in sub-optimal conditions within the next 20 to 50 years—in some parts of the country, trees may already be growing outside their optimal climates. To provide a sense of the magnitude of these changes, we present past and predicted future climate trends for Ontario and British Columbia seed zones. For Ontario, over the period 1950 to 2005, minimum temperature of the coldest month has already increased by up to 4.3°C, growing season has lengthened by up to 6 days, and precipitation during the growing season has increased by up to 26%. Changes were more pronounced across British Columbia's Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) seed zones, with minimum temperature increasing by up to 8°C, a growing season extension of up to 30 days, and growing season precipitation increases of up to 40%. Projections for the end of the current century include: minimum temperature increase of 5°C to 10°C, growing season extension of 31 to 60 days, and growing season precipitation increases of 3% to 42% across the seed zones in both provinces. These changes are certain to have extensive impacts on forest ecosystems. We briefly discuss 3 forest management adaptation strategies intended to mitigate the negative impacts of climate change in Canada.

Key words: climate change, seed zones, British Columbia, Ontario, Douglas-fir, seed transfer, assisted migration

RÉSUMÉ

Le Canada régénère annuellement plus de 400 000 ha de forêt au moyen de travaux de plantation et d'ensemencement. La plus grande partie des stocks utilisés est sélectionnée afin d'être climatiquement adaptée au site de plantation—un appariement souvent facilité par le développement de zones de provenance. Cependant, si les changements climatiques surviennent tels que prévus, les stocks qui sont adéquats sous les conditions climatiques actuelles se développeront en fonction de conditions moins qu'optimales au cours des prochaines 20 à 50 années—dans certaines régions du pays, des arbres pourraient déjà se développer dans des conditions hors des zones climatiques optimales. Afin d'illustrer l'ampleur de ces changements, nous présentons les tendances climatiques relevées dans le passé et prévues dans l'avenir pour les provenances retenues en Ontario et en Colombie-Britannique. En Ontario, pour la période de 1950 à 2005, la température minimale du mois le plus froid s'est déjà accrue de 4,3°C, la période de croissance s'est allongée de 6 jours et les précipitations au cours de la période de croissance ont augmenté de 26 %. Les changements sont encore plus prononcés pour toutes les provenances de sapin Douglas (*Pseudotsuga menziesii* [Mirb.] Franco) en Colombie-Britannique, la température minimale ayant augmenté de 8°C, la période de croissance gagnant jusqu'à 30 jours et les précipitations au cours de la période de croissance augmentant de près de 40 %. Les projections pour la fin du présent siècle sont : une augmentation de la température minimale de 5°C à 10°C, un accroissement de la période de croissance de 31 à 60 jours et une augmentation des précipitations allant de 3 % à 42 % au cours de la période de croissance pour toutes les provenances des deux provinces. Ces changements provoqueront sans aucun doute des conséquences importantes au sein des écosystèmes forestiers. Nous abordons brièvement trois stratégies d'adaptation de l'aménagement forestier dans le but d'atténuer les effets négatifs des changements climatiques au Canada.

Mots clés : changements climatiques, provenances, Colombie Britannique, Ontario, sapin Douglas, transfert de semences, migration assistée

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Introduction and Motivation

The prospect of rapid climate change has far-reaching implications for the Canadian forest sector. Projected changes in climate are expected to alter forest productivity (Grant *et al.* 2007, Savva *et al.* 2007), shift tree species' distributions (Iverson and Prasad 2002, McKenney *et al.* 2007), and change the dynamics of natural disturbances such as forest fire (Flannigan and Van Wagner 1991, Stocks *et al.* 1998, Wotton *et al.* 2005), and insect outbreaks (Carroll *et al.* 2007, Gray 2008).

There is widespread interest in adapting forest management practices to lessen climate change impacts (Lemprière *et al.* 2008). However, identifying specific adaptation strategies at local scales is extremely challenging given the uncertainty surrounding key factors such as the ultimate effectiveness of internationally-driven climate change mitigation efforts, the accuracy of global and regional climate change models, the genetic adaptation and responses of plants to rapid climate change, and forecasting the effects of unforeseen disturbance agents such as fire, pests and the introduction of alien species (Botkin *et al.* 2007). Furthermore, the relatively slow rate of forest growth in relation to the projected trajectory of climate change over the coming century makes it difficult to respond rapidly as both challenges and new information arise (Jump and Penuelas 2005).

Below, we report the magnitude of recent, and projected, changes in climate for Ontario's seed zones (Fig. 1) and British Columbia's Douglas-fir seed zones (Fig. 2). We then very briefly present 3 forest management strategies that may help mitigate climate change impacts to Canada's forest plantations. By providing a seed management context our intent is to present the challenge of adaptation strategies in a more concrete setting and stimulate broader discussion around proposed strategies. If climate change proceeds as forecast, inter-jurisdictional cooperation on such mundane matters as seed management will be critical.

Below, we report the magnitude of recent, and projected, changes in climate for Ontario's seed zones (Fig. 1) and British Columbia's Douglas-fir seed zones (Fig. 2). We then very briefly present 3 forest management strategies that may help mitigate climate change impacts to Canada's forest plantations. By providing a seed management context our intent is to present the challenge of adaptation strategies in a more concrete setting and stimulate broader discussion around proposed strategies. If climate change proceeds as forecast, inter-jurisdictional cooperation on such mundane matters as seed management will be critical.

Methods

Historical climate data

The development of a national historical climate dataset has been described in detail elsewhere (McKenney *et al.* 2006a).

Climate station data (minimum temperature, maximum temperature, and precipitation) were obtained from Canadian and US sources for the period 1901 to 2003. Models were generated using the ANUSPLIN software package (Hutchinson 2004), which employs thin plate smoothing splines to develop, spatially continuous climate surfaces. From the primary climate variables numerous other bioclimatic indices were generated using the ANUCLIM (Houlder *et al.* 2000) and SEEDGROW (Mackey *et al.* 1996) software packages. Here we present results for just 3 of those climate variables that are thought to be important determinants of seedling survival and tree growth: growing season length (GSL), average minimum daily temperature of the coldest month (MINTCM), and precipitation during the growing season (PRECGS). Due to the sparse nature of the climate station network prior to 1950 (especially in the north), we present trends for the 1950 to 2005 period. Results for more variables and other parts of the country are available upon request. The models can also be viewed on an internet mapping system at <http://cfs.nrcan.gc.ca/subsite/glfc-climate>.

Future climate data

Future climate estimates were generated using outputs from 4 General Circulation Models (GCMs). These included the Canadian GCM (CGCM2; Boer *et al.* 2000), the UK-based Hadley GCM (HADCM3; Gordon *et al.* 2000), the Australian-based Commonwealth Scientific and Industrial Research Organisation GCM (CSIROMk2; Gordon and O'Farrell 1997) and the American-based National Centre for Atmospheric Research GCM (NCAR; Collins *et al.* 2006). Here we make use of the "A2" emissions scenario (Nakicenovic and Swart 2000, IPCC 2007). This scenario forecasts rapid human population growth, heavy deforestation, increased levels of air pollution, and CO₂ emission rates that, by the end of the century, are about 3 times higher than current. Though this is considered by some as one of the more extreme scenarios developed by the International Panel on Climate Change (IPCC 2007), it describes a plausible future emissions path that can also be viewed as conservative given the rate of increase in greenhouse gas emissions in recent years (Raupach *et al.* 2007).

Raw GCM outputs were downscaled to provide greater spatial resolution by combining them with high-resolution surfaces of North American climatological normals for the 1971 to 2000 period (see McKenney *et al.* 2006b for details). Results are presented here for 3 future 30-year time periods ending on the years: 2040, 2070, and 2100.

Calculating trends

For the historic trends, Canada-wide grids of the 3 climate variables of interest were overlaid onto maps of both the Ontario seed zones and BC Douglas-fir seed zones. Mean values were then calculated for each zone and year. Historical trends were based on a linear regression between year and each climate variable of interest. An autoregressive model was used to correct for serial correlation in the error term (SAS Institute Inc. 2003). The order of the autoregressive model used for each climate variable was determined using backward elimination starting with a 12th order autoregressive model. For future climate, means were obtained for each seed zone and time period. Change values were then calculated as the difference between current (i.e., 1971–2000) and future climate values.

Fig. 1. Seed zones of Ontario.

Fig. 2. Seed zones for Douglas-fir in British Columbia. See Table 1 for full seed zone names (ZND = zone not defined).

Results

Over the period 1950 to 2005, changes in MINTCM varied from -0.8°C to 4.3°C among Ontario's seed zones, with the largest changes occurring in seed zones from the northwest of the province (Fig. 3a). Future changes in MINTCM ranged from 1.5°C to 4.2°C for 2040; 4.5°C to 7.5°C for 2070; and 7.0°C to 10.3°C for 2100 (Figs. 3b–d). The spatial pattern of the predicted changes is relatively consistent across future time periods, with the greatest changes occurring in the eastern half of the province (Fig. 3b–d). Changes across the BC seed zones for Douglas-fir are somewhat more pronounced, with increases of 2.5°C to 7.5°C between 1950 and 2003; 1.6°C to 5.6°C for 2040; 3.2°C to 7.5°C for 2070; and 5.1°C to 9.7°C for 2100 (Fig. 4a–d). Temperature increases were most pronounced in seed zones located in the northeastern region of the province.

Recent changes in GSL followed a different spatial pattern than that of MINTCM, with increases of 6 or more days in northwestern (seed zones 5 and 7), central (seed zone 24), and southwestern (seed zones 37 and 38) regions of Ontario (Table 1). Substantial increases in GSL are predicted for each of the future time periods; by the end of the century some seed zones in southern Ontario may experience growing seasons that are extended by nearly 50 days (Table 1). Recent changes in BC have been more pronounced, with growing season extensions of 10 to 30 days across the Douglas-fir seed zones (Table 2). By the end of this century, growing seasons across the BC seed zones are projected to be extended by 40 to 60 days (Table 2).

Though driven by changes in temperature, the growing season trends differ from those of the temperature variables

because growing season is calculated by accumulating the number of days that fall between a base temperature (i.e., 5°C) for initiating growth in the spring and a minimum temperature for stopping growth in the fall (i.e., -2°C). Thus, temperature increases that occur in other seasons, or below the growing season thresholds, do not affect increases in growing season length.

Historical increases in PRECGS were greatest in the southern and northwestern regions of Ontario, while little or no change has been experienced in north-central areas (Table 1). PRECGS is projected to increase over the course of this century, particularly in the central part of the province, with increases of 20% to 30% by 2100 (Table 1). Historical increases in PRECGS varied from 10% to 30% across the British Columbia seed zones (Table 2). Growing season precipitation was also projected to increase in each future time period, with the greatest increases in the southwestern and southeastern seed zones (Table 2) where PRECGS is projected to increase by 35% to 50%.

Discussion

Climate change and impacts

Our analyses indicate that substantial changes in temperature and precipitation have already occurred over the last half century across many Ontario and BC seed zones, with much larger changes predicted for the remainder of the current century. The results presented here are for only a few of the many climate variables that affect plant survival and growth. Extreme weather events (e.g., heavy rainfall, extreme temperatures, and strong winds) have also shown patterns of change over the last century that are consistent with elevated green-

Fig. 3. Change in minimum temperature of the coldest month (degrees C) across Ontario seed zones for 4 time periods **A**) 1950–2003, **B**) 2011–2040, **C**) 2041–2070, and **D**) 2071–2100. Future changes are expressed relative to the 1970–2000 normal period.

Fig. 4. Change in minimum temperature of the coldest month (degrees C) across BC seed zones for 4 time periods: **A)** 1950–2003, **B)** 2011–2040, **C)** 2041–2070, and **D)** 2071–2100. Future changes are expressed relative to the 1970–2000 normal period.

house gas emissions (Bonsal 2001, Zhang 2001, Vincent and Mekis 2006). Though not considered here, these and other weather anomalies such as freeze/thaw events may be particularly important to plant survival (e.g., Gu *et al.* 2008). We also note that the increases presented for PRECGS may be misleading in that the increased temperatures associated with climate change may also bring about higher levels of evaporation, which may nullify the predicted precipitation increases. In fact, estimates based on a climate-moisture index (Hogg 1997), which considers both precipitation and potential evapotranspiration, suggest that the water actually available to plants will decline for most forest regions in Canada by the end of this century (Lemprière *et al.* 2008).

The changes presented here are certain to have wide-reaching impacts on the growth, composition, and natural disturbance regimes of forest ecosystems—though the exact nature of these impacts is very difficult to predict. With respect to forest growth, responses are expected to vary by tree species and geographic location; trees located on the southern edge of their range would be expected to show growth declines, while increased growth is anticipated for those on the northern edge (Reich and Oleksyn 2008, Rehfeldt *et al.* 2001). This general pattern is overlaid by extreme weather events, such as the drought in the Canadian Prairies in 2000 to 2002 (Hogg *et al.* 2008) that nearly stopped the growth of Trembling Aspen on a regional scale, and by

potential growth increases that may arise in some species in response to elevated atmospheric CO₂ levels (Norby *et al.* 2005, Körner 2006).

Changes in forest composition can also be anticipated. McKenney *et al.* (2007) examined the effect of climate change on the geographic distribution of the climate habitat of 130 North American tree species. They reported an average northward shift in suitable climate of 700 km by the end of this century. Such rapid change in potential habitat will result in a major redistribution pressures for tree species across the continent. Given the northern situation and significant land base of both BC and Ontario, it is expected that suitable climate habitat will persist for most of the tree species that already occur in these provinces, while new climate habitat will be created for a number of southern species (McKenney *et al.* 2007). One major area of uncertainty is the degree to which species will track climate shifts. This will depend on natural tree migration rates, which are generally thought to be much slower than the predicted rate of climatic shift (i.e., 10–50 km/century; McLachlan and Clark 2004), and the extent to which humans assist with the migration process by establishing species in new locales (Hunter 2007, McLachlan *et al.* 2007).

Fire regimes are expected to intensify in response to climate change. Flannigan *et al.* (2005) predicted a 74% to 118% increase in annual area burned in Canada by the end of this century under recent emissions trends. Changes in insect distur-

Table 1. Changes in growing season length and precipitation for past and future time periods across Ontario's seed zones. Future changes are expressed relative to the 1970 to 2000 normal period.

Seed zone	Change in growing season length (days)				Change in growing season precipitation (%)			
	1950–2003	2011–2040	2041–2070	2071–2100	1950–2003	2011–2040	2041–2070	2071–2100
4	0.8	13.7	19.4	33.0	23.9	9.0	10.3	12.4
5	6.0	7.6	17.0	31.8	2.8	8.5	11.8	16.4
6	2.0	10.5	20.4	39.2	0.6	4.2	7.9	16.1
7	6.7	9.8	18.2	31.2	5.4	6.2	8.3	11.4
8	4.6	12.1	18.7	32.4	10.6	8.4	9.7	12.7
9	3.8	13.3	18.8	32.8	20.2	5.5	6.1	8.6
10	-1.0	14.0	19.6	33.9	33.4	1.6	2.4	3.9
11	1.7	13.4	19.0	33.8	25.3	3.2	4.0	6.0
12	5.5	16.1	22.1	36.1	21.2	5.2	6.5	8.6
13	-0.1	14.1	22.2	36.6	7.3	8.4	11.0	14.2
14	0.8	12.3	21.4	35.8	5.9	6.7	10.1	14.5
15	2.1	9.8	20.0	35.2	3.7	8.8	12.9	18.1
16	3.0	8.5	19.3	34.9	0.5	1.2	6.0	11.9
17	2.2	9.7	20.1	36.3	1.8	4.2	8.8	15.3
18	3.7	11.8	22.1	39.3	1.5	12.6	16.5	23.
19	-0.4	12.5	22.2	37.6	4.7	8.0	12.2	17.8
20	0.4	15.4	24.7	39.7	3.8	8.9	13.6	18.6
21	3.0	13.8	23.8	39.0	3.3	8.5	14.3	19.4
22	3.7	12.3	22.4	38.5	2.9	10.3	15.2	21.3
23	0.7	15.8	27.5	42.4	4.8	18.4	28.3	34.0
24	6.3	13.3	23.2	39.1	2.9	12.5	17.2	22.5
25	5.4	14.4	24.6	39.9	7.0	11.2	17.7	23.0
26	2.5	16.4	25.8	40.4	9.1	11.7	18.9	23.5
27	1.2	15.8	24.4	39.3	16.8	8.1	15.0	19.9
28	1.3	17.3	26.0	41.3	12.7	10.3	17.9	22.3
29	2.9	15.5	25.7	42.4	14.0	9.7	18.2	22.7
30	-3.6	17.1	26.4	42.9	19.8	3.9	12.3	16.3
31	0.1	17.2	25.3	40.8	12.4	6.7	14.4	19.0
32	5.4	16.3	26.2	45.7	22.8	2.6	11.1	17.6
33	5.8	16.8	25.4	43.2	21.7	7.1	15.0	20.3
34	4.7	16.2	24.8	42.6	18.2	3.9	11.7	16.4
35	-1.1	16.8	25.0	40.8	26.2	1.5	10.0	13.9
36	-2.9	15.3	23.2	38.5	22.5	4.0	13.3	16.4
37	8.1	15.3	26.0	45.1	26.1	2.4	11.3	16.9
38	10.3	16.9	29.0	46.6	25.8	2.7	10.2	14.8

Table 2. Changes in growing season length and precipitation for past and future time periods across British Columbia's seed zones. Future changes are expressed relative to the 1970 to 2000 normal period.

Seed zone	Zone code	Change in growing season length (days)				Change in growing season precipitation (%)			
		1950–2003	2011–2040	2041–2070	2071–2100	1950–2003	2011–2040	2041–2070	2071–2100
Cariboo Transition	CT	9.2	13.6	32.1	54.8	25.5	3.2	11.0	18.4
East Kootenay	EK	14.0	14.7	28.3	49.5	26.7	11.5	21.6	32.4
Georgia Lowlands	GL	17.5	7.3	28.8	43.4	11.9	-1.2	11.8	23.2
Maritime	M	30.0	12.0	32.7	59.1	14.0	11.4	25.7	50.4
Nelson	NE	14.3	15.7	29.0	51.9	28.7	6.8	15.8	27.9
Prince George	PG	16.9	15.8	30.3	47.6	21.0	9.8	18.8	29.5
Prince George/ Cariboo Transition	PGC	13.9	12.3	30.3	51.2	10.2	1.9	8.6	16.0
Quesnel Lakes	QL	17.6	17.5	32.0	52.7	22.3	14.3	26.0	37.0
Quesnel Lakes/ Nelson	QLN	18.1	16.3	29.7	51.1	32.9	12.1	22.8	35.1
Sub-maritime	SM	24.7	12.4	28.6	52.0	33.8	9.9	20.5	44.6

bance cycles are also difficult to predict under a changing climate; however, paleological data suggest that insect disturbance levels generally increase with temperature (Wilf and Labandeira 1999). The climate-induced outbreak of mountain pine beetle is evidence of the potential for unforeseen disturbance agents to arise under a changing climate (Carroll *et al.* 2007).

Adaptation strategies

Given the great uncertainty around the future of forests in Canada, many of those involved in forest management are wondering what can be done now to adapt to future change. This section discusses 3 forest management strategies intended to reduce the negative impacts of climate change on forest plantations.

Adopt seed transfer guidelines

Of the approximately one million ha of forest harvested each year in Canada, over 400 000 ha are artificially regenerated through planting or seeding operations (Natural Resources Canada 2007). The remaining area essentially uses some form of natural regeneration. While the numbers vary annually, in 1999 about 2.5 billion seeds were collected for some 36 conifer and 29 broadleaf species (Morgenstern and Wang 2001). These numbers provide evidence of the importance and scope of seed management decisions across the country; almost half of the country's harvested landbase is regenerated artificially, which potentially involves moving genetic resources some distance from their point of origin. Clearly, managers are already making important decisions about the climatic tolerance and transferability of tree seed.

To ensure that plantations being established today will be adapted to future climates, it is first necessary to ensure that systems of seed transfer controls (also called seed *procurement* or seed *transfer* guidelines) are in place throughout Canada. Effective implementation of assisted migration of seedlots (see next section) can occur only if a system of seed transfer control is in place. Further, incorporation of assisted migration will be most prudent and effective in those seed transfer systems that are based on climate. We estimate that approximately only half of Canadian jurisdictions currently employ some form of seed transfer control.

Seed selection in Ontario is based on fixed seed zones (Joyce and White 2003), which are relatively homogeneous areas with respect to key climate variables (e.g., growing season length). In fixed zone systems, seed must remain within its zone of origin. Zones are often made "operational" by drawing boundaries to coincide with nearby geographic or administrative boundaries. British Columbia also has a long history of seed transfer development (Ying and Yanchuk 2006) that has produced separate seed zone maps for improved populations of major forest species. Several approaches have been used or proposed for delineating fixed seed zones, including regression techniques (Campbell 1979), cluster analysis (O'Neill and Aitken 2004), redundancy analysis (Hamann *et al.* 2000), differential systematic coefficient analysis (Parker 2000), and maximal covering location analysis (Crowe and Parker 2005). Varying degrees of attention and information inform the maximum climatic or geographic zone width employed in fixed zones systems (see Morgenstern [1996] for an excellent discussion of these issues including the concepts of seed zones and seed transfer).

An alternative seed transfer system is the *floating* or *focal point* seed zone approach (Rehfeldt 1983, Parker 1992, Parker and van Niejenhuis 1996), which provides for greater deployability than the fixed zone approach, but requires delineating a unique deployment zone around every seed source, or a unique seed procurement zone around every plantation. The size of the procurement zone around each plantation or the deployment zone around each seed source is defined by a maximum climatic or geographic transfer distance. Statistical approaches to calculate these distances seek to maximize the productivity of the plantation on the basis of transfer functions that use provenance test data to relate provenance productivity to the climatic or geographic distance each provenance is transferred (Raymond and Lindgren 1990). Alternatively, they seek to ensure that selected seed sources are adaptively similar to the natural populations in the area of the plantation (Lesser and Parker 2004).

There are still many locations and species in Canada for which seed transfer guidelines are lacking or for which provenance data are unavailable. In such cases, simple climate matching of sites and seeds could provide a vast improvement over uninformed seed selection. "SeedWhere" (McKenney *et al.* 1999)—an example of a simple tool developed for this purpose—operates as a focal point seed zone system that scores the climatic similarity between a site of interest and each cell across a region of interest in North America. An output map of the climate similarity index allows the user to view and choose the desired level of climate similarity for seed deployment or procurement and to select the climate variables to be used in the similarity index.

Assisted migration of seed sources

Climate change will impact forest health and productivity primarily because trees' annual growth cycle will become increasingly unsynchronized with the annual climate cycles in which trees evolved, resulting in cumulative maladaptation. In addition, increased pest concerns are anticipated because as the climate changes, trees may find themselves in climates suitable to pests to which they have not developed resistance. Consequently, planting seed sources adapted to future climates (i.e., assisted migration) is a pro-active strategy that addresses the fundamental issue of the uncoupling of plant adaptation to its environment (Rehfeldt *et al.* 2006, Millar *et al.* 2007) due to climate change.

Since tree growth happens over many years, there is a trade-off between choosing seed sources adapted to current conditions but perhaps less or even poorly adapted to expected future conditions and vice versa. The choice of which time period to target when making regeneration decisions will depend on the rotation length of the species. For short-rotation species (e.g., *Populus* spp.), targeting the climate projected for the 2011 to 2040 time period is likely reasonable, while a long-rotation species may have much of its life span or economic rotation tied to the climate of the mid- or even late-century time periods.

Methods have been developed to incorporate assisted migration into seed transfer systems (e.g., Parker *et al.* 2006) or to identify appropriate climate transfer distances to account for future climate change (Wang *et al.* 2006, Beaulieu and Rainville 2005). *SeedWhere* addresses assisted migration by replacing grids of current climate with grids of future climate

of the user's choice to identify sites for seed procurement and deployment. The issue of assisted migration has been carried a step further in British Columbia, where seed transfer guidelines were recently modified to account not just for climate change in the near future, but also for climate change that has taken place over the last 100 years (O'Neill *et al.* 2008).

Assisted migration of species

To this point we have discussed assisted migration of seed sources as a key strategy to help maintain healthy and productive forests in the face of climate change. However, there is good evidence that species migration will also lag behind climate migration (Aitken *et al.* 2008). Consequently, assisting the migration of species (also called assisted colonization) has also been proposed as an important climate change adaptation strategy. Several modeling approaches have been developed to predict the migration of species' climate niches (Iverson and Prasad 2002, Hamann and Wang 2006, Rehfeldt *et al.* 2006, McKenney *et al.* 2007). As with assisted migration of populations, the climate distance species are moved will have to be small enough to allow for good survival at establishment, but large enough to ensure good adaptation toward the end of the rotation when mean annual increment is (ideally) near its maximum.

While few people object to moving seed sources within a species' current geographic range (assuming seed transfer guidelines are not violated), moving species into new areas is more contentious. McLachlan *et al.* (2007) point out that the practice is in fact already occurring and encourage politicians, policymakers, and the general public to open up discussion on the topic, focusing on the risks and uncertainty involved in such movements. Hunter (2007) builds on this foundation and suggests that work needs to be done to identify species and sites that are candidates for assisted colonization. A protocol for species movement decisions invites policy-makers to weigh the risks of migrating species outside of their current distributions (Hoegh-Guldberg *et al.* 2008). Given the precedent in forestry of introducing tree species into new locales, the forestry profession is well placed to engage in this debate.

Conclusions

Our results show historic and predicted future changes in climate in the context of Ontario and BC seed zones. Changes have been occurring over the last 50 or more years and it appears that even more dramatic changes are likely during this century. These types of spatial data are now available for any jurisdiction in the country. Climate changes are certain to impact forest growth and composition across the country but no doubt in a spatially variable manner. Assisting the migration of seed sources and species has been identified as a key response strategy to address climate change in forestry. All jurisdictions in Canada should re-evaluate their regeneration policies and, more specifically, their seed transfer guidelines to ensure that they account for not only past trends but also future prospects.

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