climate change
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Managing Tree Seed in an Uncertain Climate: Conference Summary

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Introduction

Canadian forests will experience greater increases in temperature than those growing further south. One set of projections for Ontario indicates that by the end of the century, average summer temperature will increase from 3 to 7°C (southern and northern Ontario, respectively) and that winter temperatures will increase from up to 4°C in the south to 10°C in the north (Colombo et al. 2007). Predictions of precipitation with climate change vary, but future precipitation may be insufficient to prevent large areas of Ontario forests from experiencing more frequent and intense drought (Wotton et al. 2003, Colombo et al. 2007). Such temperature and soil moisture changes would alter the ecological conditions in forests enough to affect how well trees are adapted to local climates.

As a result, climate change presents many challenges to sustainable forest management in Canada. The long life of tree species and long rotation cycles mean that the effects of today's decisions can persist for a century or more. Given projections for Ontario's future climate, those who are concerned about forest ecology, management, and policy must be concerned about seed source deployment. Important questions include:

1. What if any changes do we make in how we distribute seed sources when planting?
2. When do we make changes?
3. Can we predict the effects of such changes?

Out of concern for these issues, a conference entitled Managing Tree Seed in an Uncertain Climate was held on November 14-15, 2007, in Sault Ste. Marie, Ontario. The event was co-hosted by the Ontario Ministry of Natural Resources (through its climate change initiative) and Forest Genetics Ontario. This conference focused on managing tree seed in a rapidly changing climate, including seed movement (species and populations) and regulatory tools (guidelines/zones); the science behind identifying and predicting patterns of adaptive variation response to climate change (invited speakers' abstracts are shown in the appendix); the need to revise seed movement decisionmaking; and reforestation aspects of management planning under climate change. The goals of the conference were to:

1. Build awareness about climate change and its potential impacts on the deployment of forest genetic resources (e.g., seed transfer guidelines, seed source bulking, seed banking, and tree improvement strategies)
2. Initiate a dialogue among those concerned about impacts of climate change on forest genetic resources
3. Develop a roadmap of future actions promoting adaptation of forests to future climate

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Key Needs to Prepare to Manage Tree Seed Under Climate Change

Conference participants were asked to identify needs related to tree seed management and to rank their importance given the extent to which climate change is expected to modify the climate. A total of 91 needs were identified, and the top 5 were (in order of importance as ranked by participants; a compilation of all 91 needs is on file with Forest Genetics Ontario and is accessible at www.fgo.ca):

1. Improve information about how well tree species will adapt to changes in climate as well as identify climate variables that will be most important to species growth and survival (e.g., growing season length, soil moisture levels, and maximum summer temperatures)
2. Develop decision-support models to guide seed allocation in light of climate change
3. Generate maps and GIS grids of the ranges of future growing season precipitation (maps/grids should be as localized as possible and projected over the next rotation)
4. (a) Document cases of assisted migration (i.e., planting non-local populations or species outside their historic range) as well as new cases as they occur and monitor tree performance and local climate to aid future decisionmaking about assisted migration

   (b) Test tree species and population adaptability by planting in locations where their climate envelope (range) is expected to move (for example, if the envelope for sugar maple growing in North Bay, Ontario, is projected to move north to Timmins by 2070, begin to plant sugar maple at various locations between North Bay and Timmins and repeat every 5 to 10 years; monitor such plantings to serve as a guide for potential wider-scale planting of species and populations)
5. Determine how species will respond to climate change without intervention (how quickly will species move, and how well will each respond to a changing climate?)

Addressing these 5 needs (never mind all 91) is a huge challenge that will require support from experts in forestry, ecology, climatology, and modelling. It will require the interaction of scientists developing global and regional models with field practitioners dealing with the local and seasonal effects of climate change on trees and forests.

A Structured Approach for Planning Adaptations to Climate Change

Developing and implementing adaptation measures must be managed with care, since the extent and nature of future climate change as well as forest responses are uncertain. In addition, little is known about how most tree species adapt to their habitats and current climate.

Recently, McLachlan et al. (2007) described a framework for assisted migration, which Colombo (2008) applied to the more general theme of forest adaptation to climate change. McLachlan et al. (2007) identified 3 approaches, which vary in their intensity: aggressive adaptation, adaptation avoidance, and judicious adaptation.

Aggressive adaptation can be used if evidence shows that climate change imminently threatens forests. Taking aggressive adaptation measures implies that:

1. Climate is critical to some important aspects of forest ecosystem behaviour.
2. Projections of climate change impacts on forests are adequately known.
3. Natural adaptation will be inadequate to avoid severe effects.

Aggressive adaptation could include strategically moving a population of an endangered species well beyond its native range because its current habitat is likely to disappear in the near term. However, using aggressive adaptation could risk existing forest values. For example, an introduced species may become invasive, or an introduced population of an in situ species may not reproduce well, and the transfer of its genes into the local population could upset that species' local dominance over the long term.

The second approach is *adaptation avoidance*, which seeks to minimize the risk of causing unintended harm to natural systems (McLachlan et al. 2007). Adaptation avoidance can increase the risk of climate-driven extinction of isolated populations of species that have low adaptive plasticity. The adaptation avoidance approach relies more on allowing natural adaptation by species and ecosystems than attempting to implement planned adaptations. This strategy is preferable when projections of future climate change are highly uncertain. Where active adaptation is discouraged, strategies and policies promoting adaptation by natural processes should be encouraged, such as:

1. Conserving local populations
2. Working to lessen losses due to other threats
3. Encouraging in situ regeneration (e.g., decreasing control of natural disturbance by allowing some lower-risk fires to spread, rather than trying to suppress most fires as is now the case in many managed forests).

The third strategy outlined by McLachlan et al. (2007) is *judicious adaptation*, which seeks to balance the risks of aggressive adaptation and adaptation avoidance. This approach is based on the premise that some adaptation actions are warranted despite their risks, but risk is reduced by restricting permissible adaptations and requiring that those implemented be carefully planned and monitored. This approach is similar to adaptive management, as it includes monitoring, documentation, and evaluation. Multi-disciplinary panels of local experts and scientists could develop specific adaptation options (McLachlan et al. 2007) and prioritize them by risk level (high, moderate, low), geographic scale (large, medium, small), and temporal expectations for monitoring and evaluation (short, medium, long term).

Conclusions

Presently, forest management in general, including tree seed deployment, in Ontario is conducted using a constant-climate paradigm, in which future climate is assumed to be the same as that in the past. Since today's seed source deployment will affect forests 50+ years in the future, forest managers must begin moving towards deployment policies and practices that recognize the potential effects of climate change. Developing such policies requires that forest scientists address the needs of practical forest management, first by improving understanding of species and genotype responses to environment and second by developing models that use such information to project the response of species and populations under future climatic conditions.

How are other jurisdictions in Canada dealing with climate change in their seed transfer policies? British Columbia and Québec have already modified their seed transfer policies with climate change in mind. in Québec, the Ministère des Ressources naturelles et de la Faune, working with universities and the federal government, will soon implement seed source transfer rules for white spruce that consider projected climate change (André Rainville, Chargé de projet en amélioration génétique des arbres. Personal communication, December 2008). In addition, seed source transfer rules that account for climate change are also in development for black spruce and jack pine in Quebec (Rainville, ibid).

In British Columbia, seed transfer standards have been modified to allow seed of most species in most areas to be moved 100 to 200 m further upwards in elevation (B.C. Ministry of Forests 2008). The changes to B.C.'s seed deployment guidelines recognize the need to assist migration of tree populations to ensure plantations are adapted to projected future climates. The policy changes reflect both the climate change that has occurred in the past 100 years and the changes anticipated in the next 25 years. This interim step will be followed in 3-4 years by an entire reworking of British Columbia's seed transfer system to more fully incorporate assisted migration (Greg O'Neill, BC Ministry of Forests and Range. Personal communication, December 2008,).

Tree species changes usually occur slowly because the rate of disturbance, even in disturbance-prone boreal forests, is slow. For example, at a high rate of disturbance, such as 1% per year, the composition of 70% of the forest would change little after 30 years. Given the expected rapid change in climate and the stability of Canadian forests, considerable climate disequilibrium of species and populations is likely. A strategy of judicious assisted migration, if adopted, would allow limited, low-risk movement of species and populations, based on expert and scientific knowledge.

The conference in Sault Ste. Marie in November 2007 brought together experts in tree improvement and forest genetics from across Canada to discuss managing tree seed in light of expected climate change. These experts as well as local resource professionals identified 91 pressing needs for new knowledge about climate change effects on forest tree species adaptation. Addressing at least the top 5 needs (as described earlier) will help with decisions on how to manage existing genetic resources and allow longer-term planning of species and population genetic resource management that accounts for the effects of climate change.

Given the long-lived nature of trees, it is important that more effort be put into developing such knowledge now. It has become abundantly clear that forest management needs to take climate change and its effects on forest genetic resources into account. Responsible forest managers from government to industry to individual landowners must work together and address this challenge.

Acknowledgements

To all who participated in the conference and responded to the online survey identifying issues related to seed transfer and climate change, we express our gratitude, since your input allowed the conference organizers to gauge and document the opinions of forestry professionals on these issues. We are also highly indebted to the invited speakers who took part in the conference: Sally Aitken, University of British Columbia; Kevin Crowe, Lakehead University; Judy Loo, Natural Resources Canada; Dan McKenney, Canadian Forest Service; Jason McLachlan, University of Notre Dame; Greg O'Neill, B.C. Ministry of Forests; Bill Parker, Lakehead University; Sean Thomas, University of Toronto; and Jack Woods, Forest Genetics Council of British Columbia. For their generous contributions of time and resources, we also thank Paul Gray, Applied Research and Development Branch-MNR; Trudy Vaittinen and Bill Cole, Ontario Forest Research Institute-MNR; and Margo Shaw, ULERN. We gratefully acknowledge Forest Genetics Ontario and the climate change initiative of the Ontario Ministry of Natural Resources for financial support of the conference Managing Tree Seed in an Uncertain Climate.

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Appendix – Abstracts of Invited Speakers' Presentations (in order of presentation)

Climate Trends and Projections: Implications for Managing Tree Seed?

Dan McKenney and John Pedlar, Canadian Forest Service-Great Lakes Forestry Centre, Sault Ste. Marie, ON

We describe past trends in climate and future prospects for several Ontario seed zones as a means to help put climate change in some perspective. At larger spatial scales these interpretations are in agreement with other climate trends research. Past trends were assessed for the period 1950-2003 and prospects noted for the short, medium, and longer-term of this current century. Some trends are more obvious than others, for example, degree days and minimum temperatures would appear to be on track for large increases over the course of this century, possibly well beyond the range of natural variation over the past 50 years or so. Definitive statements about precipitation-related trends are more difficult but seasonal dryness could be a big issue due to interactions with temperature. If the climate changes as general circulation models suggest, seed zones will be experiencing weather/climate outside the range of historical variation experienced last century within the next 30-50 years.

Adaptation, Migration or Extirpation: Effects of Climate Change on Native Tree Populations

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By combining knowledge from genecology, quantitative and population genetics, genomics, and paleoecology, we can better predict the effects of climate change on native tree populations; however, outcomes are far from certain. Species distribution models predict a wholesale redistribution of trees in the next century, yet migratory responses necessary to track climate spaces far exceed maximum postglacial migration rates. The extent to which populations will adapt to new conditions will depend upon phenotypic variation, strength of selection, fecundity, interspecific competition, and biotic interactions. Populations of temperate and boreal trees show moderate to strong clines in phenology and growth along temperature gradients, indicating substantial local adaptation. Traits involved in local adaptation appear to be the product of small effects of many genes, and the resulting genotypic redundancy combined with high fecundity may facilitate rapid local adaptation despite high gene flow. Gene flow with preadapted alleles from warmer climates may promote adaptation at the leading edge of migration, while populations at the rear will likely face extirpation. Widespread species with large populations and high fecundity are likely to persist and adapt, but may suffer adaptational lag for a few generations. As all tree species will be suffering such lags, interspecific competition may weaken, facilitating persistence under suboptimal conditions. Species that have small populations, fragmented ranges, or low fecundity or that are declining due to introduced insects or diseases should be candidates for facilitated migration in a conservation context, while facilitated migration of populations will also be necessary to sustain productivity in managed forests. Field-based, hypothesis-driven tests of spatial shifts in species and population niches from species distribution models and climate change predictions should be initiated on a broad basis.

Brave New Breeding Zones

Greg O'Neill, British Columbia Ministry of Forests and Range,Vernon, BC

Climate change is expected to out-pace migration and natural selection, placing the genetically programmed annual growth/dormancy cycle of native forests out of synchrony with the annual weather cycle. Consequently, the issue of adaptation is central to understanding the impacts of climate change on forests and the range of opportunities available to address climate change in plantation forestry. Adaptation can be quantified using what are called transfer functions. Forests, forest managers, and policymakers are facing many challenges under climate change. This presentation discussed 6 innovative management options intended to mitigate the impacts of climate change on

planted forests. The array of potential reforestation strategies under climate change includes (1) assisting the migration of seedlots, (2) developing climate-based seed transfer guidelines to reduce maladaption in plantations and to facilitate assisted migration, (3) assisting the migration of species to reflect changing climate envelopes, (4) increasing the adaptive diversity of plantations by planting multiple species or multiple seedlots per species in each plantation, (5) testing exotic species for their utility in Canada, and (when climate change becomes more severe) (6) shortening rotations to replace maladapted forests with populations that are better adapted to the contemporary climate.

Genetic Effects of Rapid Climate Change After the Last Ice Age

Jason McLachlan, Notre Dame University, South Bend, IN

Longstanding reconstructions of post-glacial range expansion by trees based on paleoecological data suggest that most temperate trees expanded rapidly after the last ice age. I show that these reconstructed rates of spread are based on flawed assumptions. Independent phylogeographic data suggest that temperate trees may have spread northwards at a much slower pace. The prospect that biological constraints on population spread might limit the ability of trees to accommodate rapid climate change through spread presents a potential conservation problem in the face of modern climate warming. Assisted colonization (AC), the deliberate translocation of species or genotypes beyond their native ranges, provides a potential new management tool for addressing this problem, but it is controversial. I outline several AC scenarios for protecting species and genetic diversity and highlight their potential costs and benefits. An open interdisciplinary discussion among scientists, managers, policymakers, and the public will be required to properly assess strategies such as AC, designed to manage biodiversity under climatic change.

The Reserve Selection Problem in an Environment of Uncertain Climate Change

Kevin Crowe and William Parker, Faculty of Forestry and the Forest Environment, Lakehead University, Thunder Bay, ON

We address the problem of selecting nature reserves under multiple, equally probable climatic futures. This requires the development of 2 models: (i) a model forecasting the change in a tree species' distribution under a given climate regime, and (ii) an optimization model to maximally cover as many species in as many climate scenarios as possible, given a constraint on the total reserve area available. This approach is applied to a case study involving 63 native tree species for the entire province of Ontario. Future climate scenarios are based on output from multiple climatic scenarios produced by the following general circulation models: Canadian Global Coupled Model (GCM), the Hadley Centre's Model, and the GCM of the Commonwealth Scientific and Industrial Research Organization.

Natural Migration, Assisted Migration and Climate Change: What Will Nature Do, and What Will We Have to Do for Nature?

Dan McKenney, Canadian Forest Service-Great Lakes Forest Centre, Sault Ste. Marie, ON

If projections of general climate models are correct, major biogeographic pressures will cause the climate habitat of most tree species to shift hundreds of kilometres over the course of this century. The Canadian Forest Service is conducting an Internet-based project to develop and map the climatic tolerances of hundreds of plant species, now and under several climate change scenarios. Maps plus metadata on climate tolerances for more than 2,000 species can be viewed at planthardiness.gc.ca. While all parts of the continent will be affected, Ontario and Quebec may not be as "relatively" affected as other regions. Our future efforts will include developing alternative modelling strategies as well as intervention strategies that reflect current and projected climate envelopes, land use change pressures, and growth rates. Resource managers should keep in mind that much uncertainty is associated with assessing potential impacts from climate change thus adaptive management is challenging. Nevertheless, we may also need to act quickly with "assisted migration" programs if climate changes as dramatically as the scenarios suggest.

Comparison of Seed Transfer Function and Focal Point Seed Zone Approaches in Present and Future Climates

William H. Parker and Ashley M. Thomson, Faculty of Forestry and the Forest Environment, Lakehead University, Thunder Bay, ON

Climate is the overarching factor determining tree growth and distribution. Predicted shifts in climate are expected to impact Ontario's boreal tree species. The growth data obtained from provenance tests provides help in predicting species' responses to climate change. In 2005, height, diameter and survival data were obtained from 16 of the North American tests of the 255 Series Range Wide Jack Pine Provenance Tests containing 99 sources. These data were related to present climate conditions, and the resulting models were used to predict future growth performance in 2050 using 2 approaches: univariate response functions based on the Cauchy function and multivariate focal point seed zones (FPSZ). Spatially explicit results based on 3 general climate models (GCMs) and 2 scenarios differed between the response function and FPSZ approaches and among the FPSZ models based on different GCMs. The observed disparity in the results obtained by the 2 approaches, and especially the disparity in the results based on the different GCMs, indicates a high level of uncertainty regarding the need for and destination of seed source transfers.

Coordinating Gene Conservation for Climate Change Action Plans: A Role for CONFORGEN

Judy Loo, Tannis Beardmore, and Dale Simpson, Canadian Forest Service-Atlantic Forestry Centre, Fredericton, NB

Climate change is expected to rearrange the patterns of adaptation associated with geographic variation, posing new challenges and requirements for Canada's forest genetic resources. These challenges transcend jurisdictional boundaries, and a coordinated approach is needed to assemble and report on information on the status of forest genetic resources. This is an important component of a rational planning response to climate change. CONFORGEN (a Canadian programme for conservation of forest genetic resources) is an initiative of a pan-Canadian network of forest tree genetics experts that provides a framework for such a coordinated approach. CONFORGEN was formally initiated at a Canadian forum on forest genetic resources in summer 2006. A steering committee has been established representing provincial forest genetics councils, provincial governments, 1 territorial government, and Natural Resources Canada. As well, a technical committee, consisting of provincial, federal and academic experts, has been established. CONFORGEN is now seeking recognition as a subgroup within CCFM (Canadian Council of Forest Ministers). Four areas of work are being undertaken by CONFORGEN. First, we will conduct a survey to reevaluate the status of native tree genetic resource conservation needs in various jurisdictions across Canada. This survey was conducted previously by CONFORGEN members, and we expect that each iteration will provide more precise information. Second, we will work with CAFGRIS (Canadian Forest Genetic Resource Information System, accessible through National Forest Information System [NFIS]) to compile, summarize, and present Canada-wide genetic resources conservation data. CAFGRIS will be available as a platform for provinces, industry, universities, and others to use to synthesize relevant forest genetic resources information and assist in developing strategies to respond to climate change. Third, we plan to extend a gap analysis that will determine the status of native tree genetic resources and the gaps in their conservation across Canada. Finally, we plan to develop science-based guidelines for assessing and conserving Canada's forest tree genetic resources, responding to threats from climate change and other stressors.

Developing a Comprehensive Change-Management Plan

Jack Woods, Forest Genetics Council of British Columbia and SelectSeed Co. Ltd., Duncan, B.C.

Stable climate has been an underlying assumption of seed zone development and tree improvement programs. Climate change negates this assumption and requires planning and management that considers dynamic seed zones that will migrate geographically in uncertain ways over time. This uncertainty is not constant with time, however, as climates can be forecast with reasonable confidence in the near term but with decreasing confidence for periods further in the future. In addition, geographic zones of deployment will increasingly diverge from the geographic areas from which seed or genotypes were originally procured.

On predominantly public land in most parts of Canada, geographic seed zones are developed by a provincial agency, and industrial licensees and provincial programs adhere to these zones in their planning for operational reforestation activities, including seed procurement, seed inventory maintenance, seedling production, planting programs, and tree improvement activities such as progeny testing, selection, and seed orchards. Changing seed zones has an impact on all operations concerned. Where decisions to modify seed zones are made, it is important that the implementation allows all affected operations to adjust and to re-deploy human and capital resources in anticipation of the changes. Managing for this change at policy, operational, and research levels should entail commitment to a long-term change-management structure.

Seed zone and public-land policy changes should take place approximately every 10 years, with a minimum of 5 years advance notice of actual zone changes. Advance notice is necessary to provide surety to operations and to allow for the adjustment of human and capital resources (such as seed orchards) within a reasonable and known time frame. Such a process will create operational certainty within a longer period of highly uncertain change. Decade-long intervals will also allow a reasonable time frame to develop research towards the next change milestone, and all changes will be focused on the ensuing period of 10 or 15 years, a period in which climates may be forecast with some degree of confidence.

In British Columbia, substantial research and expertise is focused on climate change questions. At this time, however, we have not developed a comprehensive and long-term change-management plan. In this presentation, I discuss the elements of such a plan for addressing climate change in the context of the diverse forest environments, complex timber licensing systems, and large orchard-seed production systems in British Columbia.

La gestion des semences d'arbres dans un climat incertain : Résumé de la conférence

D'après les projections relatives au changement climatique, l'Ontario connaîtra des hausses de température et un risque de baisse de l'humidité du sol. Ces changements se répercuteront à un point tel sur les conditions écologiques que les arbres des peuplements locaux, voire des espèces indigènes, pourraient mal s'accommoder des climats locaux. Cette menace ainsi perçue était le thème de la conférence Managing Tree Seed in an Uncertain Climate (la gestion des semences d'arbres dans un climat incertain), tenue les 14 et 15 novembre 2007 à Sault Ste. Marie, en Ontario. La conférence visait à sensibiliser et à discuter en matière de changement climatique et de ses répercussions éventuelles sur les ressources génétiques des forêts, ainsi qu'à indiquer la voie à suivre pour de futures mesures qui faciliteraient l'adaptation des forêts aux climats à venir. Les personnes qui ont participé à l'atelier ont établi 91 besoins scientifiques, les cinq plus importants consistant à :

1. Améliorer la compréhension de la façon dont le changement climatique influera sur les espèces d'arbres
2. Concevoir des modèles d'appui aux décisions pour guider l'attribution des semences
3. Acquérir des gammes de projections pour les futurs niveaux de précipitations et l'humidité disponible des sols
4. (a) Étayer les cas antérieurs de migration assistée et (b) mener et surveiller des études sur la plantation de peuplements et d'espèces d'arbres dans les lieux pour lesquels on prévoit une migration
5. Mieux connaître l'aptitude d'espèces à répondre au climat en l'absence d'intervention humaine

Pour relever les défis que lance l'adaptation des forêts au changement climatique, il faut une approche bien pensée qui permettra d'établir des politiques et des pratiques proactives. En outre, il faut intensifier la recherche pour améliorer la compréhension des réactions des espèces et pour intégrer cette connaissance, ainsi que les projections de futurs climats, dans une structure de modélisation.

Cette publication hautement specialisée *Managing Tree Seed in an Uncertain Climate: Conference Summary* n'est disponible qu'en Anglais en vertu du Règlement 411/97 qui en exempte l'application de la Loi sur les ser les services en français. Pour obtenir de l'aide en français, veuillez communiquer avec au ministère des Richesses naturelles au information.ofri@ontario.ca

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