Canadian Council of Forest Ministers
Conseil canadien des ministres des forêts

Adapting Sustainable Forest Management to Climate Change:

A Review of Assisted Tree Migration and its Potential Role in Adapting Sustainable Forest Management to Climate Change

This report is a product of the Climate Change Task Force of the Canadian Council of Forest Ministers.

Copies of this report in French and English can be found online at ccfm.org or by contacting the Canadian Council of Forest Ministers.

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Adapting Sustainable Forest Management to Climate Change:

A review of assisted tree migration and its potential role in adapting sustainable forest management to climate change

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Canadian Council of Forest Ministers
Climate Change Task Force

"Consideration of climate change and future climatic variability is needed in all aspects of sustainable forest management"

A vision for Canada's forests: 2008 and beyond

(CCFM 2008)

Photo: IStockphoto.com/michael1959

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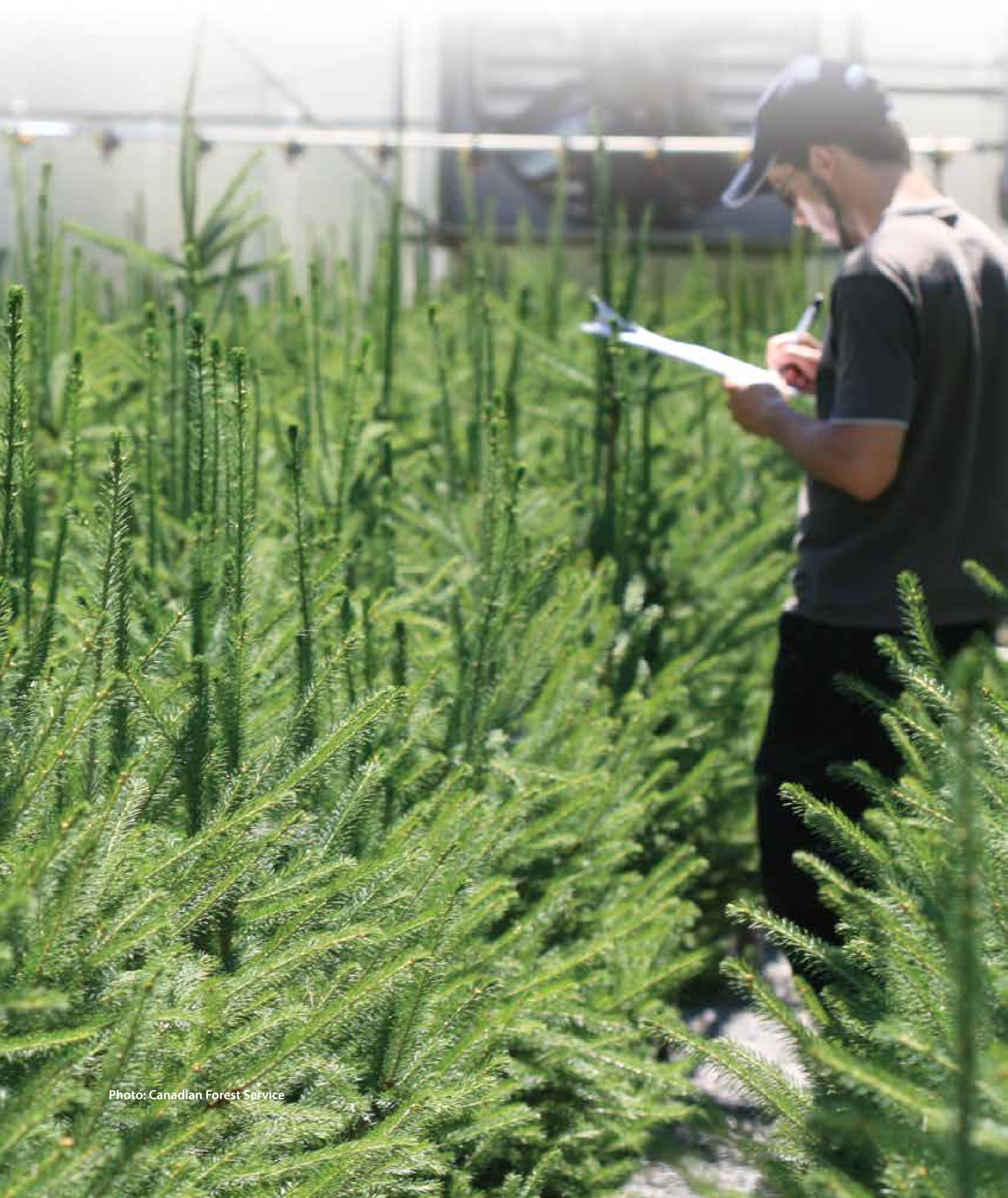

Photo: Canadian Forest Service

FOREWORD

Canada has 397 million hectares of forests and other woodlands, representing 10% of the world's forest cover. Our forests constitute a world-class natural treasure providing ecological, economic, social, and cultural benefits to all Canadians, regardless of whether they live in small northern communities or large urban centres. Canada is committed to sustainable forest management, which aims to maintain and enhance the long-term health of forested ecosystems while providing ecological, economic, cultural, and social opportunities for present and future generations.

One of several factors that pose both opportunities and challenges in terms of effectively and efficiently meeting our sustainable forest management goals is climate change and its inherent uncertainties. The Canadian Council of Forest Ministers (CCFM) identified climate change as one of two priority issues for Canada's forest sector. In its *Vision for Canada's Forests: 2008 and Beyond*, the CCFM stated, "Consideration of climate change and future climatic variability is needed in all aspects of sustainable forest management." In addition, to minimize the risks and maximize the benefits associated with a changing climate, Canada's provincial and territorial premiers asked their Ministers responsible for forest management to collaborate with the federal government on adaptation in forestry through the CCFM's Climate Change Task Force. Phase 1 of this work, completed in 2010, involved a comprehensive assessment of the vulnerability of various tree species and identified management options for adaptation. Phase 2 has gone beyond the level of trees to look at climate change adaptation within forest ecosystems and the broader forest sector. The goal of phase 2 was to equip members of the forest sector with a suite of tools and state-of-the-art information to enable them to make better decisions about the need for adaptation and the types of measures that may be most beneficial.

Over a period of two years, nearly one hundred individuals from a wide range of organizations have contributed to achieving this goal. The fruits of their labour have been captured in the CCFM's Climate Change Adaptation series, which comprises several technical reports and review papers. It is our sincere hope that these documents, which will be used in conjunction with workshops, seminars, and presentations, will benefit forest practitioners from coast to coast to coast as they seek innovative ways to adapt sustainable forest management policies and practices for a changing climate.

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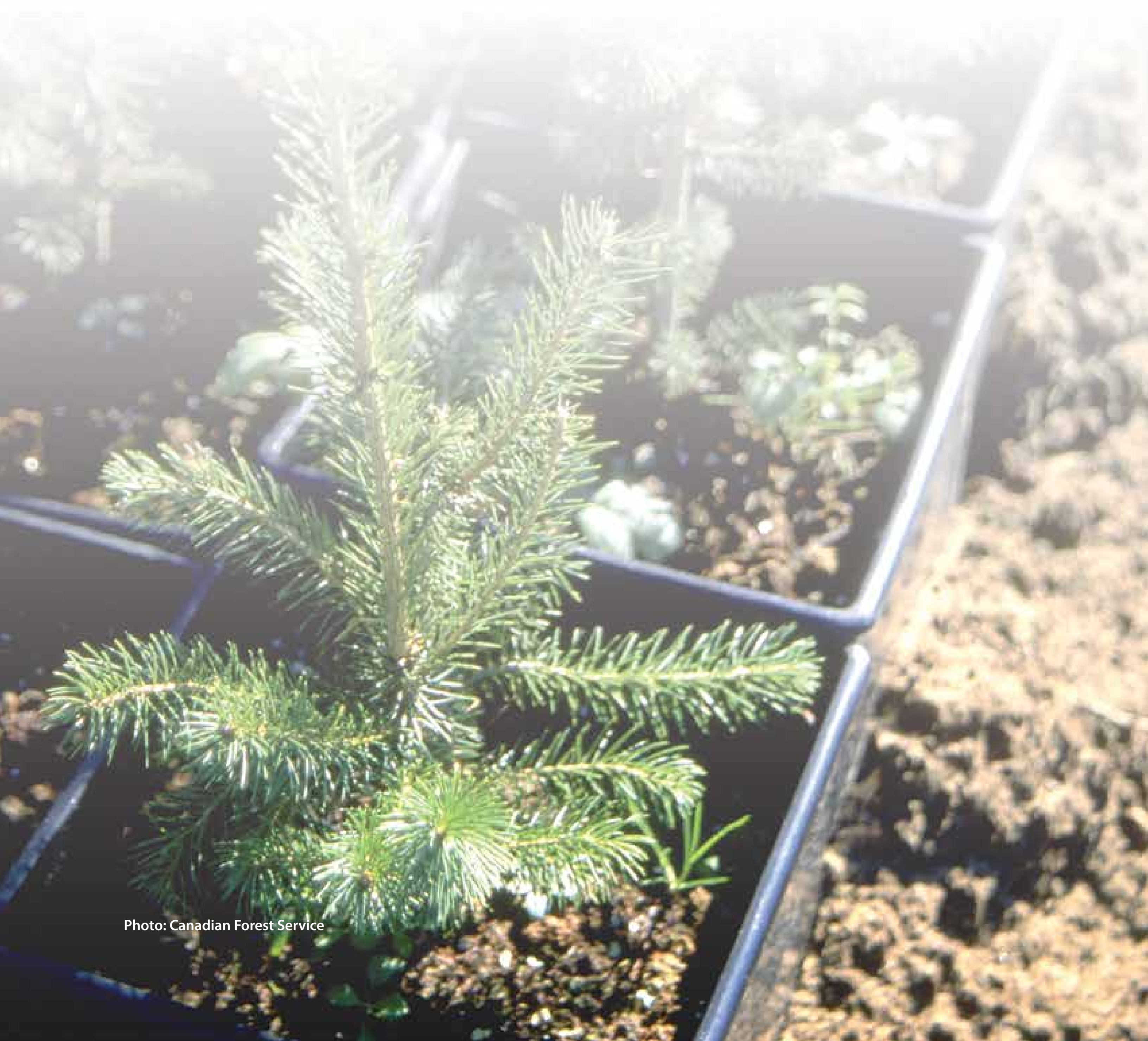
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ABSTRACT

Many options have been proposed to adapt forest management to the effects of climate change. One of these options, assisted migration of tree species, is now being explored by forest managers. Forests have historically adjusted to changes in climate on their own. Today, however, the climate is changing much more rapidly than ever before, and there is a risk that tree species may be unable to genetically adapt or migrate quickly enough. The term "assisted migration" refers to human intervention to deliberately move species to new, more favorable locations, with the goal of helping them to survive and flourish in a changing climate. Implementing assisted migration poses new and complex scientific, social, and ethical questions. This summary report provides an overview of assisted tree migration, describes many of the potential opportunities and risks associated with this strategy, and outlines current thinking on responsible implementation of assisted migration of tree species. Informed and open discussion among all players with an interest in the future of Canada's forests will be key to exploring the assisted migration option. This report seeks to provide a balanced overview to inform the emerging dialogue on this topic.

Key words: Assisted migration, assisted colonization, managed relocation, range expansion, climate change, adaptation, forest.

RÉSUMÉ

Plusieurs options permettraient d'adapter l'aménagement des forêts aux effets des changements climatiques. L'une d'elles, la migration assistée d'espèces d'arbres, est en train d'être analysée par les aménagistes forestiers. Historiquement, les forêts se sont toujours ajustées par elles-mêmes aux changements du climat. Cependant, la rapidité inégalée des changements climatiques actuels est telle que les espèces d'arbres ne seront peut-être pas capables de migrer assez vite ou de s'adapter génétiquement à ces changements du climat. L'expression « migration assistée » renvoie au déplacement délibéré d'espèces par l'humain vers de nouveaux emplacements plus favorables à leur croissance, dans le but de les aider à survivre et à se développer sous de nouvelles conditions climatiques. L'implantation de la migration assistée pose des questions nouvelles et complexes aux plans scientifique, social et éthique. Ce rapport décrit en aperçu ce qu'est la migration assistée d'espèces d'arbres, et plusieurs des avantages et risques potentiels, et présente les questions actuelles que suscite son application responsable. Explorer la migration assistée devra aller de pair avec une discussion ouverte et éclairée entre tous les acteurs intéressés par l'avenir des forêts au Canada. Ce rapport présente une vue d'ensemble du sujet, en vue d'alimenter adéquatement les discussions émergentes le concernant.

Mots clés : migration assistée, colonisation assistée, relocalisation planifiée, expansion de l'aire de distribution, changement climatique, adaptation, forêt.

CONTENTS

INTRODUCTION

The vast forests that cover 54% of Canada's landmass provide ecological, economic, cultural, and social benefits to the population. As development pressures on forest resources have mounted, a concept of forest management has come to the fore that ensures healthy forests for future generations while allowing for a balanced, equitable, and efficient flow of benefits for current generations. This approach, known as sustainable forest management (SFM), is now widely embraced by forest managers across Canada. In 1992, Canada became one of the first countries to voluntarily endorse a United Nations statement of principles on the sustainable management of forests. Canada is also the country with the largest area of forest certified as meeting the forest management standards of independent, nonprofit, national and international bodies.

In the face of climate change, however, it is becoming more challenging to achieve SFM goals. Forests have historically adjusted to changes in climate through genetic change (i.e., adaptation) and through changes in geographic distribution (i.e., migration to more favorable locations). Today, the climate is changing much more rapidly than ever before. Given the long life span of trees, some lasting hundreds of years, and the slow pace of migration and regeneration, tree species may not be able to genetically adapt or migrate quickly enough.

Certain forest tree species are able to take advantage of increases in temperature to increase their growth in some regions, but many species face serious risks from climate change. Changing temperature, moisture, timing of seasons, and distribution and abundance of insects and disease could threaten their health and survival. Canada has already experienced many examples of such effects. Hot, dry summers have led to an increase in the number and severity of forest fires, such as those that caused extensive damage in British Columbia in 2003, Alberta in 2011, and Ontario in 2012. Some insects and diseases may flourish with warmer temperatures, finding new hosts and territories. For example, an explosion in the population of the mountain pine beetle has affected swaths of pine forest in western Canada and the United States.

What is sustainable forest management?

Sustainable forest management (SFM) maintains and enhances the long-term health of forest ecosystems for the benefit of all living things, while providing ecological, economic, cultural, and social opportunities for present and future generations (CCFM 2008). The Canadian Council of Forest Ministers (CCFM 2006) has defined the following criteria to aid in achieving and monitoring SFM in practice:

1. Biological diversity
2. Ecosystem condition and productivity
3. Soil and water
4. Role in global ecological cycles
5. Economic and social benefits
6. Society's responsibility

[CCFM] Canadian Council of Forest Ministers. 2006. Criteria and indicators of sustainable forest management in Canada: national status 2005. Ottawa, ON. 154 p.

[CCFM] Canadian Council of Forest Ministers. 2008. A vision for Canada's forests: 2008 and beyond. Ottawa, ON. 15 p. Also available at: <http://www.ccfm.org/pdf/Vision_EN.pdf>

Droughts of unusual severity, extent, and duration have also damaged forests. For example, drought led to the dieback of large areas of trembling aspen forest in Saskatchewan in 2001–2002. Given the breadth of these effects, there is concern that inability to adapt to a changing climate could lead to the loss of certain tree species in particular regions (extirpation) or even to extinction of one or more species.

In an SFM context, many options have been proposed to adapt forest management to the effects of climate change. One of these options, assisted migration of tree species, is now being explored by forest managers. Implementing assisted migration poses new and complex scientific, social, and ethical questions. This summary report provides an overview of assisted tree migration, describes many of the potential opportunities and risks of this strategy, and outlines current thinking on responsible implementation of assisted migration of tree species. Although the concepts and practices of assisted migration could be applied to other components of forest ecosystems, such as other plants or animals, such broader application is beyond the focus of this report. As well, this report does not address the full scope of natural capital values arising from forest ecosystems.

Examples of risks to forests posed by climate change

- **Increases in annual mean temperature**
  - Effects on health and survival of native species
  - Increase in pest activity
  - Invasion of exotic species
- **Changes in precipitation**
  - Unusual droughts causing dieback
  - Increase in number and severity of forest fires
  - Flooding
- **Changeable weather, including warm springs and late frosts**
  - Early budding, followed by killing of buds by frost
  - Absence of cold snaps in winter or fall that would typically kill insects
- **Severe ice, snow, thunder, and windstorms**
  - Trees damaged, weakened, struck by lightning, or blow down

ASSISTED MIGRATION: A NEW CONTEXT FOR AN OLD PRACTICE

The idea of assisted migration first appeared in the media in 1998 and has been the subject of a growing number of scientific studies and media stories since 2007. Various terms are used for this concept (see "Definitions," below), but in brief, it refers to human intervention to deliberately move species to new, more favorable, locations to help them to survive and flourish in a changing climate. It is an idea that is generating considerable scientific research as well as debate.

Humans have moved plant species since the inception of agriculture, mostly without public discussion or scientific study. Throughout history, crops have been moved to new locations and planted widely; in fact, most crops grown in Canada are not native to this country. Similarly, many of the ornamental plants for Canadian lawns and gardens are exotic species from other countries. Just about any street in any Canadian city or town is home to several non-native tree species.

As described in this report, assisted migration is different from previous transplanting initiatives in that it would be based on scientifically rigorous advice developed in response to the need to manage for climate change. However, it is important to recognize that there are potentially positive and negative outcomes associated with assisted migration, which require careful consideration.

This report draws on the most recent information available on assisted migration, including five articles published as a theme issue of *The Forestry Chronicle*:

Aubin, I.; Garbe, C. M. ; Colombo, S. ; Drever, C. R. ; McKenney, D. W.; Messier, C.; Pedlar, J.; Saner, M. A.; Venier, L.; Wellstead, A. M.; Winder, R.; Witten, E.; Ste-Marie, C. 2011. Why we disagree about assisted migration: ethical implications of a key debate regarding the future of Canada's forests. Forestry Chronicle 87(6): 755–765.

Beardmore ,T.; Winder, R. 2011. Review of science-based assessments of species vulnerability: contributions to decision-making for assisted migration. Forestry Chronicle 87(6): 745–754.

Pedlar, J.H.; McKenney, D.W.; Beaulieu, J.; Colombo, S.J.; McLachlan, J.S.; O'Neill, G.A. 2011. The implementation of assisted migration in Canadian forests. Forestry Chronicle 87(6): 766–777.

Ste-Marie, C.; Nelson, E. A.; Dabros, A.; Bonneau, M. E. 2011. Assisted migration: introduction to a multifaceted concept. Forestry Chronicle 87(6): 724–730.

Winder, R.; Nelson, E.A.; Beardmore, T. 2011. Ecological implications for assisted migration in Canadian forests. Forestry Chronicle 87(6): 731–744.

Opportunities

In an SFM context, successful assisted migration could allow human communities to continue to benefit from healthy, productive forests, not only in their roles as providers of raw materials and environmental services, such as biodiversity, habitat, clean water, and carbon storage, but also in terms of their broader economic and social benefits, including jobs, spiritual values, and recreation.

Assisted migration is proposed as one method to save species that are threatened with extinction or extirpation in a particular area because of climate change. It has also been proposed as a means of bolstering existing forest ecosystems, maintaining their productivity or vigor, and maintaining their resilience to natural disturbances, such as drought, fire, and pests, which are projected to become more frequent under a changing climate.

Two incremental forms of assisted migration considered to pose lower risks are starting to be implemented in Canada as a means of achieving many of the goals of SFM: assisted population migration and assisted range expansion (see "Definitions", above). The aim of assisted population migration is to increase genetic diversity, by helping the tree species to cope with threats related to climate change and to take advantage of opportunities for increased growth due to warmer temperature. Since 2001, this practice has been implemented in forestry operations in some parts of Canada. For example, in Quebec, seed transfer models that take climate change into account have been developed and are being used to determine the locations where seedlings produced from seeds grown in seed orchards can be planted for the best chances of survival and growth to maturity.

Assisted range expansion is also being implemented in Canada. The government of British Columbia has recently allowed seeds of most species in most regions to be planted 200 m higher in elevation, and has allowed western larch to be planted slightly outside the existing range of this species, to areas where the climate is deemed suitable for its growth. The government of Alberta is similarly changing seed zone limits by extending them by up to 2° northward in latitude and by up to 200 m upward in elevation. These measures acknowledge that a warming climate opens areas farther north and at higher altitudes for certain northern species.

Both population migration and range expansion are considered to represent the lower end of the spectrum of potential risk of ecosystem damage or invasiveness, since the tree species is moved a short ecological, geographic, or climatic distance within or just beyond its current range. Trials of tree species growing at different locations, such as provenance trials, have been carried out in Canada for 50 years without any reports of ecological impact.

The third type of assisted migration, assisted long-distance migration, is considered for species conservation in cases of severe threat or geographic barriers (such as urban concentrations, lakes, and mountains) preventing natural migration. This type of assisted migration is considered to pose higher risks, both of failure and, conversely, of damage to the recipient ecosystem. No assisted long-distance migration projects are currently planned by Canadian forestry agencies.

One of the first attempts at assisted long-distance migration has been organized by a citizens' group, the Torreya Guardians, in the United States. Torreya taxifolia is a coniferous species that has suffered a critical decline in its natural range in northern Florida. The Torreya Guardians have planted the tree in new locations in the states of Georgia, Tennessee, Ohio, and North Carolina, where it is reported to be growing well. Without assisted migration, such groups argue, species such as Torreya taxifolia could be lost forever, affecting biodiversity.

Definitions

Assisted migration | The human-assisted movement of species in response to climate change (also called "assisted colonization" and "managed relocation")

Assisted migration can take three forms:

Assisted population migration | The human-assisted movement of populations (with different genetic makeup) of a given species within that species' current range (i.e., where it would naturally spread)

Assisted range expansion | The human-assisted movement of a given species to areas just outside its current range, assisting or mimicking how it would naturally spread

Assisted long-distance migration | The human-assisted movement of a given species to areas far outside its current range (beyond where it would naturally spread)

Risks

There are inherent risks with any decision to engage in assisted migration. For example, even if its preferred temperature range is matched in a new location, differences in day length, rainfall, or soil properties (such as nutrient levels, drainage, and acidity) could affect growing conditions and the probability of survival of the migrated trees. For example, many tree species rely on mycorrhizae (fungi living in symbiosis with plants) in the soil to help protect their roots and to bring in water and nutrients. A lack of the mycorrhizal symbionts or other companion organisms could hinder attempts to relocate the species. For this reason, some researchers have suggested assisted migration not only for the tree species, but also for many components of its surrounding ecosystem, including portions of the forest floor.

Beyond the need for companion organisms, a species moved to a new location could face infestations by diseases, insects, and predation by animals that were absent at the original site and would also have to compete with other plants in the new ecosystem.

Even if the environmental setting is suitable, planting specimens of one species of uniform age and genetic background can make a new forest vulnerable to, for example, an insect or a disease that targets that species. To maximize the chance of success and to reduce stresses like those described above, trees of the same species with diverse genetic makeup, from different source locations, could be planted together in the new location. To replicate the diversity of the source forest, new areas could be reforested to have trees of different species, ages, and ecological stages.

There is also the risk that even well-researched attempts to move trees to new areas will founder because of ecological "surprises." This risk grows with the distance over which the trees are relocated and with increased divergence between the characteristics of the trees' original site and the target location. The risks of assisted migration can be mitigated by starting with small, experimental plantings that are carefully controlled and monitored to assess their viability.

The other key risk is that assisted migration will succeed too well, with the introduced species becoming invasive in its new environment. The aim is to have the newly introduced species thrive without causing negative consequences for native species or host ecosystems. The potential for invasiveness is now well recognized because of earlier inadvertent and deliberate species introductions; however, most invasive species are animals and herbaceous plants, rather than trees, so this risk may be limited in the context of SFM. Although a few tools are now available to assess the risk that a species will become invasive, invasion biology is still an emerging science and much remains to be learned about how and why some species run amok after they are introduced to a new location.

"Risk exists on all sides of the AM [assisted migration] debate—risk of inaction, risk of unsuccessful action, and risk of being too successful (i.e., creating novel invasive species)."

Mueller, J.M.; Hellmann, J.J. 2008. An assessment of invasion risk from assisted migration. Conserv. Biol. 22:562–567.

Beyond the potential for invasiveness, introducing a species to the complex ecosystem of a forest can have other unforeseen ripple effects. An introduced species may displace other tree species by competing for resources such as light, moisture, and nutrients, or by changing the nutrient dynamics or moisture content of the soil. Furthermore, changes to a forest's composition can change the habitat for fungi, insects, mammals, understory vegetation, and other organisms. A tree species that has been moved to a new location may interbreed with local species to produce hybrids, altering the genetic diversity of the local population. Ultimately, though, this may have beneficial effects for the genetics of both species.

Another risk is that an introduced species may carry with it or attract new diseases, undesirable or unwanted plants (weeds), or insects to an ecosystem. In Canada, for example, there is concern about warm-climate insects and diseases moving northward. Some insects that were previously unable to survive harsh Canadian winters can now overwinter. Insects tend to be more mobile than plants and can outpace the natural migration of their host species, readily finding new territories and new hosts. In the context of SFM, these risks can be minimized by introducing tree species in a controlled setting, as closely monitored experiments or trials, for a reasonable period before planting is expanded.

New ways to make decisions in these uncertain conditions are continually emerging. It is generally agreed that the best available ecological knowledge should be used, with the acknowledgment that uncertainty is always a factor. For assisted migration, decision making has to take into account the risk that climate change poses to the species, as well as the feasibility and suitability of assisted migration.

Values-based perspectives

The range of views on assisted migration arises not only from concerns about the ecological risks outlined above, but also from deeply held values regarding the relationship of humans to nature and from differing visions of the future. For example, some people believe that assisted migration is just another example of humans meddling with nature, that the risks outweigh the gains, and that it should be avoided. Conversely, others believe that assisted migration is a justifiable management strategy with reasonable chance for success using scientific knowledge and professional practices. Some believe that applying technology to problems caused by climate change is an abdication of the responsibility to stem human activity causing climate change, whereas others believe that unprecedented challenges like climate change call for unprecedented actions, including assisting species to adapt to situations that humankind has created. Hence, in considering assisted migration, values-based perspectives may be difficult to separate from ecological and operational viewpoints.

IMPLEMENTATION OF ASSISTED MIGRATION

When assisted migration is being considered, it is important to address several key questions:

- Which species are vulnerable to climate change and could benefit from assisted migration?
- Would introduction of the candidate species be detrimental to their new environment?
- How far do candidate species need to be moved to ensure their health and productivity?
- How would target locations be selected?
- Where would seeds come from?
- How can the chances of success be increased and the risks mitigated?

Species vulnerability to climate change

In considering assisted migration, forest managers and government agencies will need to select from among the candidate species that would benefit most from being moved. The main drivers in this choice are community support, conservation of species at risk and maintenance of commercial viability for forests of economic value. The primary challenge is to determine which tree species are most vulnerable to climate change.

The general understanding of the vulnerability of tree species to climate change is limited by gaps in scientific knowledge concerning the response of trees to unprecedented changes in climate factors and their capacity to adapt genetically. Furthermore, if a species has experienced a recent decline, it may be difficult to determine the extent to which the decline was due to climate change, as knowledge of the biology and environment of many tree species is incomplete and continuously evolving.

Several science-based tools have been developed to help evaluate whether a tree species is vulnerable to climate change, information that can then support decisions about assisted migration. All of these tools use a set of criteria concerning the response of a species to climate change, integrating this information by means of a spreadsheet or list. These tools are still evolving and will be further developed over time. It must also be borne in mind that decision-support tools are only as good as the data available for analysis, and such data are currently lacking for some tree species.

One of these tools, the Index for Predicting Tree Species Vulnerability, is being developed specifically for Canadian tree species. Using biological information in published reports, the index assesses a species' vulnerability to climate change in terms of several factors, including its ability to migrate and to adapt in place, as well as its resilience and environmental buffering capacity. The index has so far been tested with nine Canadian tree species. Other tools have been developed and used in the United States and could likely be modified and applied in the Canadian context.

Determination of risk

After identifying candidate species and determining their priority for assisted migration, managers would need to determine the potential of the species to disturb the new ecosystem, as described in more detail in "Risks," above. Plans for assisted migration should include testing, monitoring for early detection of negative impacts of the introduced species and of other species introduced along with the tree on recipient ecosystems, and taking measures to mitigate the risks.

Legislative regime for assisted migration in Canada

Of Canada's vast forested area, 93% is publicly owned. Forests, as a natural resource, fall mainly under provincial or territorial jurisdiction. In accordance with the Canadian Constitution, provinces own and regulate natural resources on their territory. They have exclusive authority to develop their own legislation, standards and programs to assure the development, conservation and management of forest resources. Territories are also responsible for managing their own resources. The federal government may also manage forest resources when responsibility for the land falls under a federal department or agency or when a provincial government has asked the federal government to do so.

Provincial or territorial and federal forestry legislation normally provides for timber harvesting under license, afforestation and reforestation, and government authority for and intervention in management. Federal, provincial and territorial legislation may also cover conservation activities such as the creation of nature reserves. Many provinces and territories have mandated sustainable forest management in their legislation.

As well, if forestry harvesting and reforestation affect the future of a particular tree species, or of other species in the forest (such as insects and animals), provincial or territorial and federal legislation governing conservation, wildlife protection, and endangered species can come into play. Some laws and regulations recognize plants and trees as potential species at risk. Furthermore, many provinces and territories have regulations and strategies to conserve biodiversity, to guide adaptation to a changing climate, and to manage natural resources sustainably.

In Canada, a citizen-led assisted migration effort, like the replanting of Torreya taxifolia in the United States (which involves use of only private land), would be restricted by the paucity of privately owned forests. Furthermore, a license from the relevant government is required for planting in publicly owned forests, and most provinces and territories regulate the import of plants that are not native to the province or territory.

Future assisted migration efforts would entail careful determination of their adherence to applicable legislative regimes, as well as approval of and guidance from the relevant governments at all stages.

Photo: Canadian Forest Service

Migration distance

A key question in implementing assisted migration is how far the species would need to be moved to ensure long-term survival. Moving a species too far may result in poor seedling survival, but not moving it far enough may lead to failure to counteract the effects of climate change.

Matching the climate where the species currently grows to the projected future climate at the planting site has been proposed as a straightforward approach to determining the appropriate migration distance. However, because the climate has already changed in the past century, some researchers have suggested that the climatic conditions to which a population is adapted should be based on the climate that has prevailed for the last two to four generations of trees. Also, the future climate cannot be projected with certainty, so it is impossible to predict precisely which planting sites would be suitable for a given species in the years ahead.

There is also the issue of how far into the future climate should be projected for the purposes of planning assisted migration (e.g., 25, 50, or 100 years). For commercial trees that are typically grown for 75 years before harvesting, some researchers have proposed targeting the climate anticipated after one-third of the rotation (i.e., 25 years), because trees are most sensitive in their first decade of growth. However, the future target time could vary with the species and the objectives of a particular migration project.

The mean annual temperature in southern Canada was about 1°C cooler at the beginning of the 20th century than it is now, at the beginning of the 21st century, and is expected to increase another 1°C in the next 25 years. As such, some have proposed that species be moved to planting sites with a current temperature about 2°C cooler than the temperature at the source site.

Another approach to this question is the use of data from provenance trials to calculate a critical seed-transfer distance, the maximum geographic or climatic distance that seed can be moved and still generate plants that grow and reproduce. Data from provenance trials are currently held in various systems and databases. Improved coordination and integration of such data from different sources would allow access to better information and would help in identifying gaps in the existing data.

Target sites for seeds and planting

Finding suitable seed sources and planting sites is not as simple as consulting maps of projected future temperatures, however. Other climate variables, such as rainfall, are equally important in identifying suitable locations. Computer applications have been developed to help match current seed sources to future planting sites. One example is SeedWhere, developed by researchers within the Canadian Forest Service of Natural Resources Canada and the Ontario Ministry of Natural Resources. This application calculates an index of climatic similarity between one seed site or planting site and many others, specifically to help plan assisted migration. Development of such a tool to aid in seed selection nationwide will be beneficial for future assisted migration efforts.

During site selection, it is also necessary to consider regional differences in the effects of climate change. However, projections of regional effects vary among the models used to project future temperatures, rainfall, and other variables at the regional level. To address for this variation, one approach involves using multiple climate scenarios and multiple species distribution models to find areas where the future projections are in agreement. Another option is to plant a given site with seeds originating from a variety of locations, to maximize genetic diversity and augment the chances that some seeds will do well in the new climatic zone (the portfolio effect). Statistical calculations can also provide additional information to minimize risk and maximize adaptive capacity.

Seed sources

Ensuring that seed procurement and storage systems are adequate for regeneration of both commercial and non-commercial species is also a subject of concern. Seeds are regularly collected from commercial tree species for reforestation efforts, both from wild trees and from seed plantations in most Canadian provinces. Existing collection and storage systems could be assessed to ensure they will meet Canada's future needs. There is also concern that climate change may affect seed production, as fluctuating spring temperatures can cause failure of tree reproduction. As well, seeds for noncommercial tree species are not widely collected or stored.

The National Tree Seed Centre of the Canadian Forest Service plans to collect and store representative samples from throughout the natural ranges of all Canadian tree and shrub species. Seeds have been collected from about 100 species so far. Such collections will provide a measure of "species insurance" for conservation or restoration, in case of species decline or extinction. However, they also have limitations, since some tree species, such as oaks, do not tolerate long-term or frozen seed storage.

In the future, optimal seed sources for Canadian assisted migration projects may be located farther south, in the United States, and the seeds will therefore be subject to the import regulations that govern plants. However, Canada may wish to establish production areas for seeds that would normally be imported from the United States, to ensure a secure seed supply in the future.

Planting the seeds of success

In any assisted migration effort, once a seed source area and a target planting area have been identified, a specific planting site needs to be pinpointed. Commercial reforestation historically has involved planting in areas that have been previously harvested, whereas future assisted migration may also target areas where forest has been lost to fire, disease, or pests. As well, suitable new locations may be sought for a threatened species. Finding new locations poses additional challenges, including current land cover, soil attributes, and site topography. Geographic information systems may be used to help select sites, or broad-scale land cover maps may be combined with aerial photographs and field surveys. For species requiring special conditions such as canopy openings to germinate and grow, it may be necessary to alter the existing forest to create a suitable site.

Planting is just the beginning of the assisted migration process. Whereas guidelines and practices are in place for reforestation with commercial species, such guidelines do not exist for the noncommercial species that will be moved by assisted migration. Carefully monitored experimentation will enable researchers to define a number of factors for each species, such as the following:

- whether planting seeds or seedlings has the best result
- which season (spring or fall) is best for planting
- whether the site or soil needs to be prepared
- which seed sources perform best
- whether seeds from different sources should be planted randomly across a site to maximize genetic diversity or in blocks (according to the respective sources) to facilitate monitoring of trials

In the face of uncertain future climate conditions at a given site, the chances of success can be increased by planting seeds from a variety of locations, as trees from different provenances (source locations) are adapted to different conditions. Genetic diversity can give certain species an "edge" in resisting diseases and insects and in coping with variable conditions. As mentioned earlier, assisted migration in forest landscapes that naturally include a variety of species, ages, and ecological (seral) stages could aim to reproduce the diversity found in the source location.

Managing the newly planted stands (with watering; weeding; controlling insects, diseases, and other predators; and managing competing vegetation) may be helpful, but may not be feasible for cost and logistical reasons. Experimentation and evaluation can help to determine whether such measures will be needed.

Monitoring new tree stands for potential negative impacts, as well as for the success of the migration effort, can contribute to mitigating the risks to other native species of plants and animals at the planting site. Because trees are immobile and because they grow and reproduce slowly, assisted migration experiments can be curtailed if a serious risk is found. Measures are needed to manage the risks of assisted migration at all stages of the process.

Assisted migration carries a variety of costs, for careful planning, seed procurement, transportation of seeds or seedlings, seed import fees, planting, tending, and monitoring. These costs will vary with the particular project. For expansions of regular reforestation of commercial tree species, the costs would probably be only modestly higher than current costs. For assisted migration of species of conservation concern, the costs could be considerable. In either case, the economic, social, and environmental costs need to be weighed against anticipated benefits in deciding on priorities for assisted migration.

MOVING FORWARD

Assisted migration is an emerging concept, and one of the management strategies being considered in the face of accelerating climate change, to conserve tree species and the benefits that forests provide. However, questions remain about the potential risks of and the appropriate forms for assisted migration, as well as about differences in values concerning the role of human intervention in nature. Both proponents and opponents of assisted migration are motivated by the protection of nature, and both groups agree that assisted migration has associated risks, in particular, the risk of failure and the risk of altering fragile ecological balances beyond the degree of alteration that would occur without human intervention.

A decision to move forward with assisted migration requires the best scientific and technical knowledge available to inform policies and guide practices, taking account of the complex web of scientific, economic, and social factors involved. In Canada, provinces have the authority over forestry, and each one is expected to go forward at its own pace, depending on prevailing local factors.

Informed and open discussion among all players with an interest in the future of Canada's forests will be key to exploring the assisted migration option. This report has sought to provide a balanced overview to inform the emerging dialogue on this topic.

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GLOSSARY

Adaptation | Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory, autonomous and planned adaptation:

> **Anticipatory adaptation |** Adaptation that takes place before impacts of climate change are observed. Also referred to as proactive adaptation.
>
> **Autonomous adaptation |** Adaptation that does not constitute a conscious response to climatic stimuli but is triggered by ecological changes in natural systems and by market or welfare changes in human systems. Also referred to as spontaneous adaptation.
>
> **Planned adaptation |** Adaptation that is the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state (Parry et al. 2007).

Adaptive capacity | "The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences" (Parry et al. 2007).

Climate | "Climate in a narrow sense is usually defined as the 'average weather', or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. These quantities are most often surface variables such as temperature, precipitation, and wind. Climate in a wider sense is the state, including a statistical description, of the climate system. The classical period of time is 30 years, as defined by the World Meteorological Organization (WMO)" (Parry et al. 2007).

Climate change | "Climate change refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the United Nations Framework Convention on Climate Change (UNFCCC), which defines 'climate change' as: 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods" (Parry et al. 2007).

Ecosystem | "The interactive system formed from all living organisms and their abiotic (physical and chemical) environment within a given area. Ecosystems cover a hierarchy of spatial scales and can comprise the entire globe, biomes at the continental scale or small, well-circumscribed systems such as a small pond" (Parry et al. 2007).

Extirpation | Local extinction; a species or subspecies disappearing from a locality or region without becoming extinct throughout its range (Côté 2003).

Genetic diversity (genetic variation) | The variation in the genetic composition of individuals within or among species, varieties of breeds, heritable genetic variation within and among populations (Côté 2003).

Invasiveness | Ability of a plant to spread beyond its introduction site and become established in new locations where it may provide a deleterious effect on organisms already existing there.

Migration | In forest research, the movement of large seed-plant–dominated communities in geographic space over time.

Provenance | The original geographic source of seed, pollen or propagules (Côté 2003).

Resilience | "The ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organization, and the capacity to adapt to stress and change" (Parry et al. 2007).

Rotation | The period of years required to establish and grow even-aged timber crops to a specified condition of maturity (Côté 2003).

Seed zone (seed transfer zone) | A designated area, usually with definite topographic bounds, climate, and growing conditions, containing trees with relatively uniform genetic (racial) composition as determined by progeny-testing of various seed sources (Côté 2003).

Vulnerability | "The degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity" (Parry et al. 2007).

Literature Cited

Coté, M. 2003. Dictionnaire de la forestie / Dictionary of Forestry. Ordre des ingénieurs forestiers du Québec. Sainte-Foy, Qué. 473 p.

Parry, M.L.; Canziani, O.F.; Palutikof, J.P.; van der Linden, P.J.; Hanson, C.E., Eds. 2007. Appendix I: Glossary. In Climate change 2007: impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge Univ. Press, Cambridge, UK, and New York, NY.

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