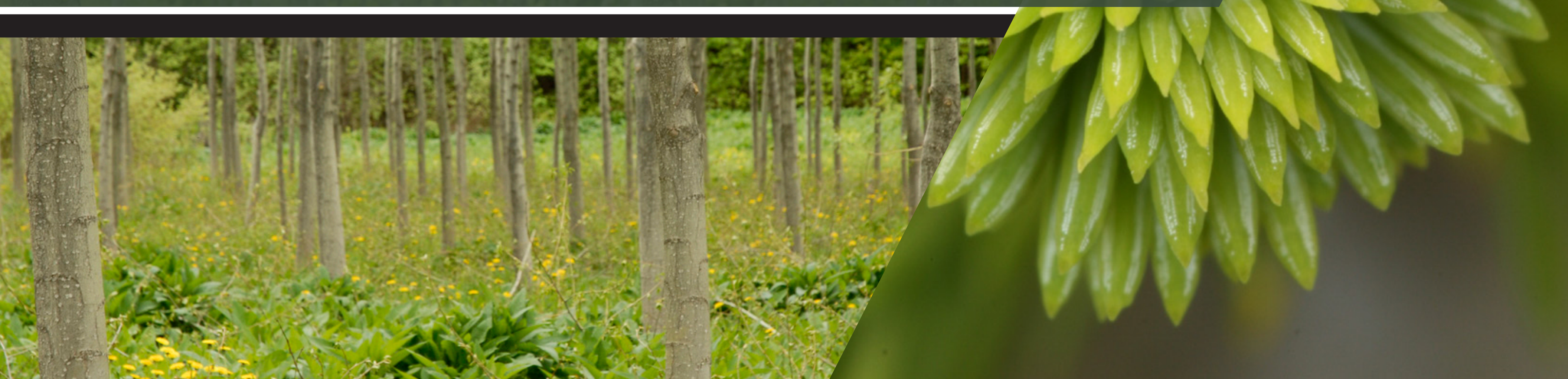
The science at the Canadian Forest Service in genomics and climate change in relation to the 2 Billion Trees Program



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Inside cover – potted seedlings on agricultural land, Association forestière des deux rives; planted trees in urban area, Association forestière des deux rives.

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Background

In 2020, the federal government committed to implementing natural solutions to fight climate change. It established a program with the goal of planting two billion trees over ten years to help Canada reduce its greenhouse gas emissions by 2030.

The trees planted will help Canada fight climate change by absorbing carbon dioxide, one of the main greenhouse gases. In addition to sequestering carbon through photosynthesis, trees provide important ecological services such as improving air and water quality as well as controlling soil erosion. They provide food, shelter and shade for many organisms, and help increase biodiversity. Trees also play a major spiritual and cultural role for many Canadians, including Indigenous peoples, and they provide social and economic services such as green jobs. Planting specific species near communities can help reduce the risk of forest fires and flooding. Tree planting also creates spaces for recreational activities, thereby improving the well-being and quality of life of Canadians.

Although the planting process may seem simple at first glance, it requires time and cooperation between the various organizations involved. Science also has an indispensable role to play, especially within the context of climate change. The right tree must be planted in the right place and requires proper monitoring. To provide the benefits listed above, several pre-planting steps are required, namely thorough planning. From sowing seeds in the nursery, to planting seedlings, to monitoring trees, the program's success is dependent on its many current and future partners and collaborators.

The Canadian Forest Service (CFS) at Natural Resources Canada contributes to research on national forestry issues. This brochure encompasses current knowledge stemming from research in genomics and climate change as it relates to the 2 Billion Trees Program. This knowledge is presented based on an integrated approach that is part of a broader context with the intent of making it accessible to organizations and stakeholders involved in this vast plan. Such research is conducted in partnership with several academic, government and private organizations.

What is genomics?

DNA is present in every organism. DNA consists of four types of nitrogenous bases (represented by the letters A, T, G and C). Sequencing these letters together “creates words and sentences” (genes) to “write a book” (genome), thereby encompassing billions of letters. The genome, a word stemming from the words gene and chromosome, therefore carries all the genetic information contained in each cell of a living organism. It can be compared to an instruction manual enabling cells to fulfill their various functions.

Genomics is the study of genetic material of living organisms (plants, animals, humans or microorganisms), both in terms of structure and functions. With advances in sequencing techniques for decoding DNA, this science has grown at a remarkable rate over the last twenty years. Its applications are making it possible to advance knowledge in various sectors such as human health, agri-food, fisheries and aquaculture, mining, energy, the environment and… forestry, all within a context of adaptation to climate change!

A precious tool in the fight against climate change

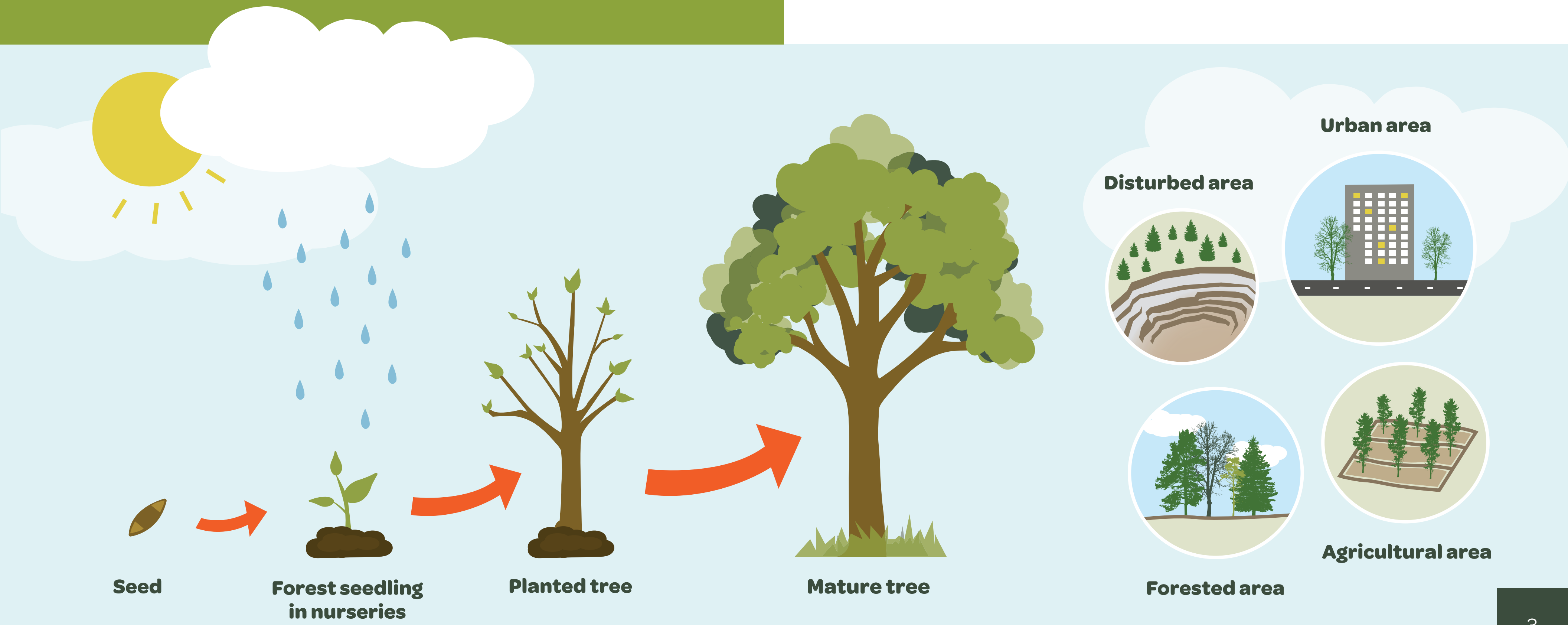
As is the case all over the planet, Canada’s forests must contend with climate change. Given its northern placement and large surface area covered by forests, scientists expect that climate change disruptions in Canada will be more significant than the planetary average. The expected rate of climate change is expected be ten to a hundred times faster than the natural adaptability of forests. These changes will have an impact on the distribution of plant species, the composition of ecosystems and, consequently, the health and productivity of natural and managed forests. They will also have an impact on trees in urban and periurban areas.

Under these circumstances, genomics, used in conjunction with other approaches, can help us prepare for the challenges created by climate change, namely by providing a better measurement of the impacts on the productivity and health of forests, as well as increasing resilience.

Current models assume that all trees respond in the same way to climate, which is far from reality. By integrating the genomic variability of trees into this model, scientists may, among other things, be able to characterize tree populations based on their response to a type of change (e.g., frost, drought or increased carbon dioxide). This will make it easier to select the appropriate seedlings for reforestation or to prioritize certain actions to ensure that certain species will adapt well to the climate change expected over the next 10, 20 or 30 plus years in a given region. It was within this perspective that researchers identified genes closely linked to drought resistance in white spruce. These results remain to be validated with data from other experimental study sites for white spruce.

Whether it is to validate the origin of seeds, contribute to conservation efforts of threatened or declining species or to detect forest pathogenic agents in nurseries, genomics can play an important role in the fight against climate change at various phases of a tree's lifecycle or in its environment.

CFS research teams are at the forefront of research in genomics and climate change. Here is an overview of some of their work supporting the 2 Billion Trees Program. This work is directly related to the basic concepts of planting projects.



An integrated approach to climate change adaptation

Climate change is creating complex problems in ecosystems, which themselves are fundamentally very complex. The integration of data and knowledge from various disciplines is increasingly essential to finding solutions and achieving desired outcomes. Pedology, entomology, pathology, forest ecology and research on climate change and genomics are all disciplines that should be considered when planning a tree-planting project.

The right tree in the right place for the right use

Trees with multiple functions

A tree's growth extends over several decades. Therefore, it is important to plan and take into account several aspects beforehand while ensuring the right tree is planted in the right place. Questions regarding tree planting (where, how, which ones, why) need to be asked. Although they may appear simplistic, these questions are vital, as the planted tree will live there for several years! Species diversification is another essential aspect. A green space containing several species is less vulnerable to forest pests. Just consider the damage caused by the emerald ash borer, an invasive pest that is decimating ash trees in North America.

The objectives of a planting project must be clearly defined so as to meet the needs of the organization undertaking it, as well as the needs of the community that might use the selected site or benefit from the planting.

The role of trees to be planted must be properly defined, as this can have an impact on the choice of species. These roles may include the creation of a green space, reduction of heat islands, reduced soil erosion and biodiversity rehabilitation or improvement, to name but a few.

For example, in urban areas, a tree's growth habit, its size at maturity or resistance to road salt are elements to be considered. When restoring a site that had been used for other purposes (e.g., an old mine), it might be preferable to select slow-growing trees to allow the soil to build up nutrients gradually. In agricultural areas, the combination of certain species can influence wind movements, thereby protecting arable land. Abiotic conditions (soil, drainage, temperature, precipitation) as well as biotic conditions (insects and diseases) are also factors to consider.

Each tree species has particular needs in terms of light and precipitation. Therefore, when choosing species, site characteristics must be considered. Drainage conditions, soil or deposit type (texture) and variables such as slope position must be analyzed in order to plan the prerequisite steps to planting and to ensure the success of plantings. For example, compacted soil will probably need to be loosened, whereas certain types of soil will offer conditions that are less conducive to the survival and growth of specific species.

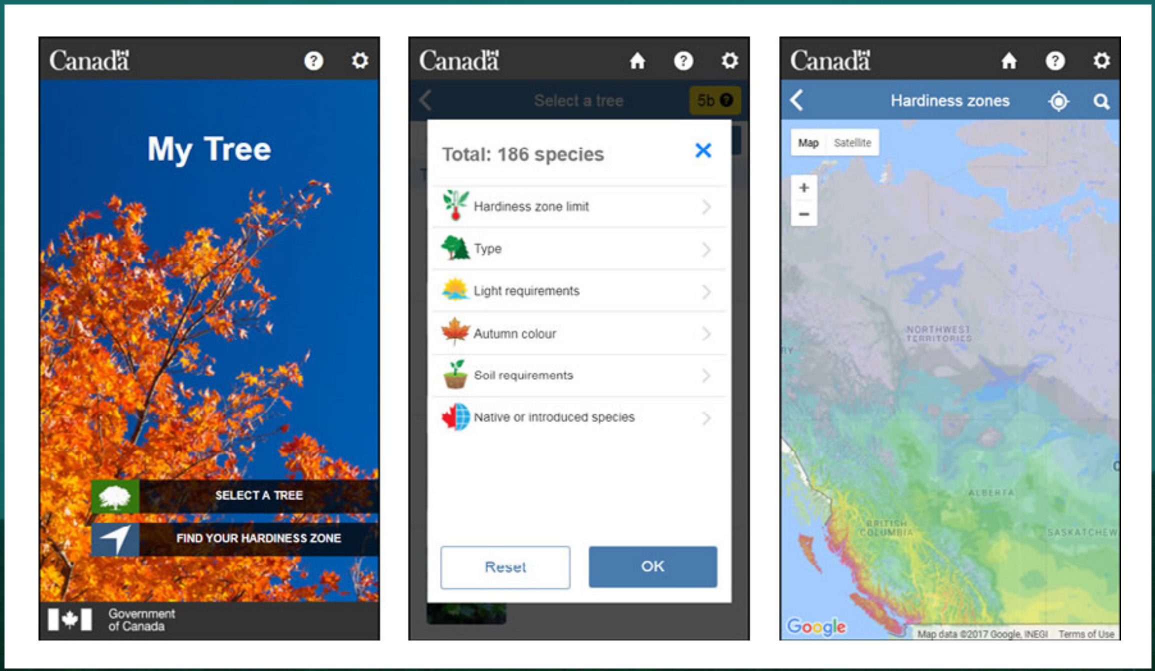
A practical app

To assist in selecting the right trees, the free My Tree app, developed by Natural Resources Canada, provides information on trees that are best adapted to a given region. The app includes more than 180 native and introduced tree species. Users can personalize their searches based on tree type (coniferous or deciduous), soil moisture, light requirements and the choice of native or introduced species.

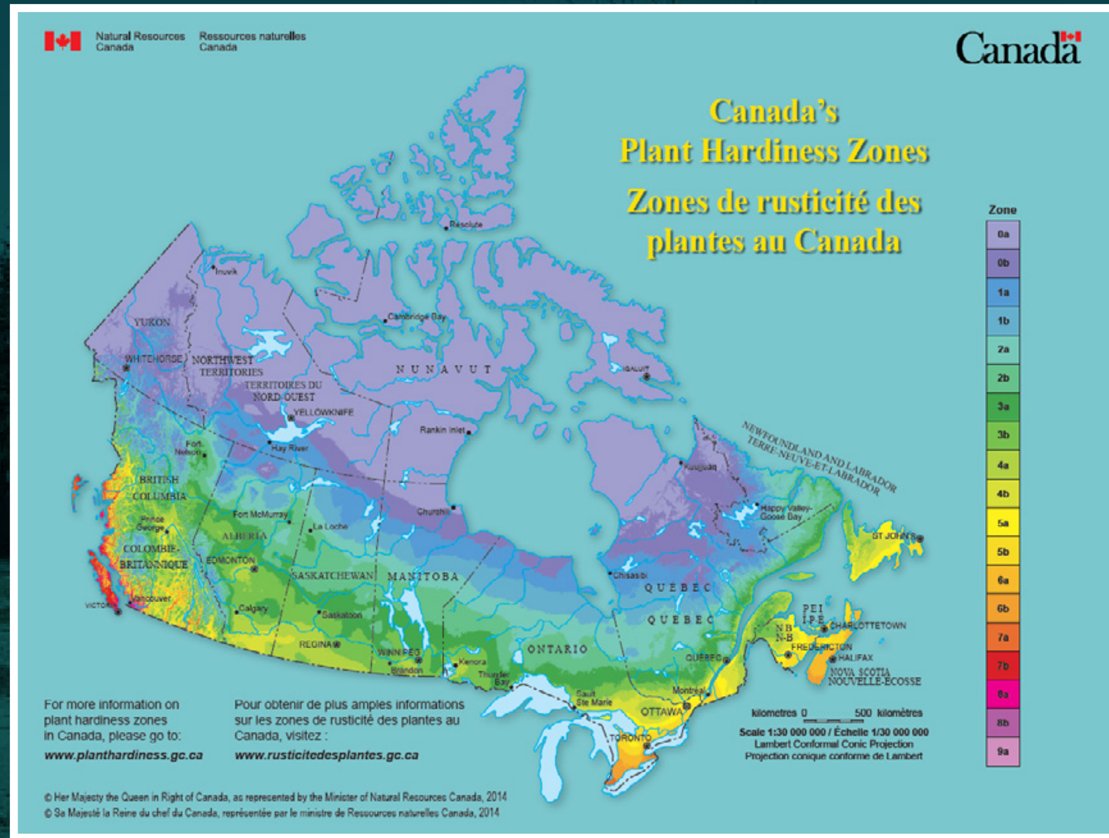
This app uses the Plant Hardiness Zone Maps developed by the Government of Canada, which describes ten climate zones based on factors such as maximum and minimum temperatures, the frost-free period and precipitation. A plant hardiness zone is a geographic area where the climate conditions are suitable to the growth of various types of plants.

My Tree also provides information on the main characteristics of trees, including height, light requirements, soil requirements, autumn colour and species origin (native or introduced). Information provided for each species comes mainly from the CFS publication, *Trees in Canada*.

You can download **My Tree** mobile app on your iOS or Android device.



Since the plant hardiness zone maps were established in 1960 by Agriculture and Agri-Food Canada, the CFS has published various updates. Researchers have found that plant hardiness zones are changing due to climate change, and it is happening at a faster rate in certain regions of Canada. For example, when comparing the original maps with the most recent ones, certain regions in northern British Columbia have warmed to the point where they have moved up three plant hardiness zones. In fact, sections of Vancouver Island are now considered 9a, a zone that had not previously existed in Canada. Although changes in Eastern Canada are less striking, they are still notable and associated with climate change. Recent updates to the plant hardiness zones help take climate evolution into account and could lead you to consider species or varieties that you had not previously considered.



In addition to the general information from Canada's plant hardiness zones, more detailed maps on the growth potential of each species for a given area are available. The plant hardiness zone site currently provides Species-specific Models and Maps applicable to more than 3000 plant species. Its objective is to develop the potential distribution for various species of trees based on climate change scenarios for different periods.

Tree planting in risk areas

With the number and scope of forest fires increasing in many regions, the potential dangers must be evaluated by the involved communities and home owners. They are invited to follow the recommendations listed on the website, "Be fire smart." For example, the website suggests selecting fire-resistant plants and deciduous trees for landscaping around homes. Indeed, the wildfires in Fort McMurray, Alberta in 2016 and the ones in Lytton, British Columbia in 2021 have raised awareness that in boreal forests, deciduous trees should be planted around cities and villages rather than evergreens, which have a much higher potential for combustion.

In flood prone zones, it would be better to plant species that are adapted to shorelines; willows, for example. In certain cases, the right choice of species can also limit the damages caused by wave action.

Restoration of disturbed sites

Human activity, combined with climate change, can affect soil quality and productivity. One of the solutions considered by scientists to re-establish lands disturbed by natural resource exploitation uses the microorganisms (microbiome) present in the soil. They play an essential role in nitrogen and carbon cycles, help plants better assimilate certain nutrients and contribute to the breakdown of complex compounds, such as hydrocarbons and other pollutants. The function for the latter is called phytoremediation.

Using genomics, CFS research teams can compare the microbiome of undisturbed soils to that of environments disturbed by various human activities. By studying the identity of microorganisms in the soil and their roles in relation to soil characterization, it is possible to identify the biological indicators of environmental stress. These indicators then serve to better predict the impact of various disturbances and to conduct monitoring during the rehabilitation of disturbed sites. Such studies also make it possible to determine best plant-microorganism combinations for restoring disturbed sites. This data will contribute to the successful restoration of sites such as logging roads and mining sites.

Other CFS research teams are working on an interactive planning tool for restoring multiple ecosystem functions. This tool will help in selecting mixes of plant species, as well as specifying their quantities based on specific restoration objectives.

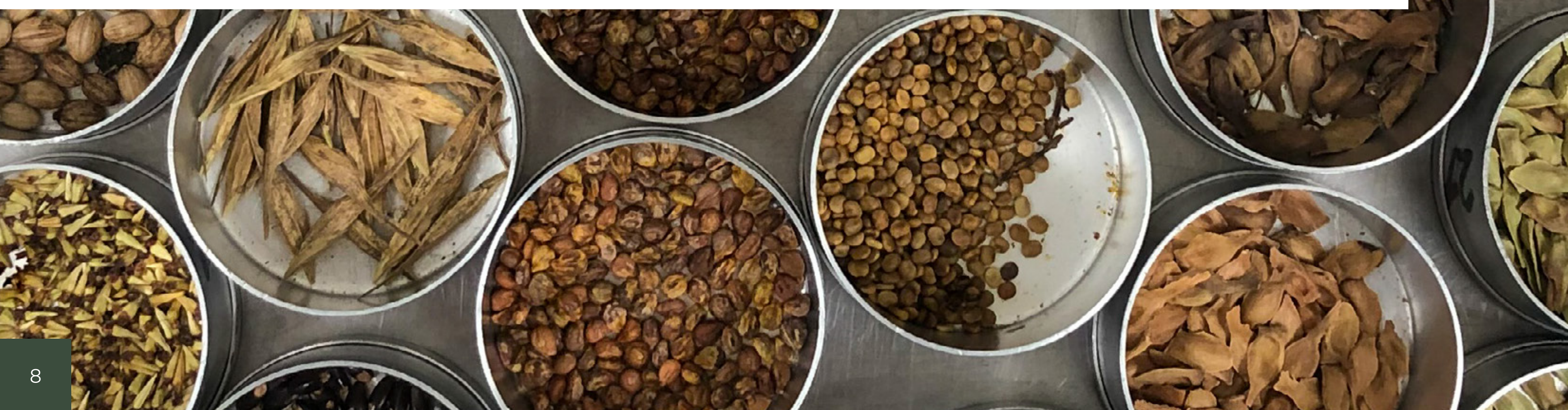
A toolkit presenting various approaches for the restoration of disturbed sites has been developed by Canada's Oil Sands Innovation Alliance (COSIA) in collaboration with Natural Resources Canada.

Diversified seeds: a good start

Genetic diversity represents all genetic variations present in a given population or species. This diversity is essential in terms of evolution and adaptation. In certain planting projects, namely those looking to solve a forest health or adaptation problem, it is necessary to take genetic diversity into account when choosing which trees to plant.

CFS's National Tree Seed Centre (NTSC) is the only national seed bank dedicated to preserving the genetic diversity of Canadian forests. In a sense, it is Canada's library of forest genetic resources.

The seeds available today for genomics and climate change research encompass nearly 133 species of trees and shrubs, spread out over more than 10,900 collections. Among them are reference collections that have established important CFS-wide provenance tests. The NTSC's national seed bank also includes 68 other species, which are spread out over more than 6,300 long-term collections kept specifically for programs aimed at restoring species at risk. These mostly unique collections are generally georeferenced to provide climate information to genomics researchers or to determine the suitability of seed transfer to sites in anticipation of changing climate conditions.

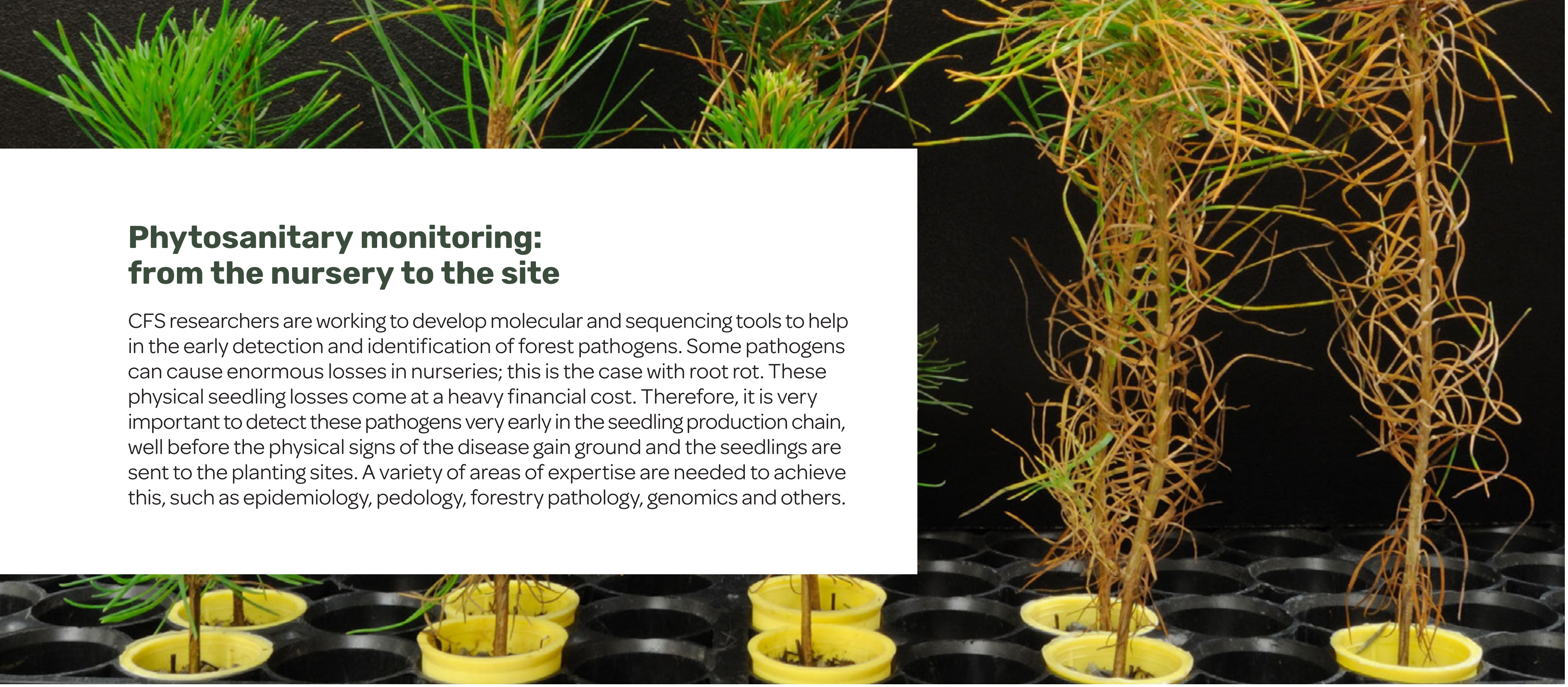


Genetic conservation programs

The National Tree Seed Centre (NTSC) offers genetic conservation programs for specific species to remedy possible threats. If needed, seed banks could provide material for future studies or restoration programs. For example, the NTSC is the main Canadian repository of ash seeds (in response to the emerald ash borer threat), hemlock seeds (in response to the hemlock woolly adelgid threat), as well as butternut and five-needled pine seeds (e.g., whitebark pine and limber pine), which have been placed under long-term cryopreservation.

The NTSC is leading a national assessment of ecologically appropriate seed supply to support large-scale nature-based solutions. It was designed to assess the availability of native seeds, the stakeholders involved in the seed supply chain in Canada, as well as the short-term organizational capacity and needs throughout the country.

The NTSC offers knowledge and training adapted to the needs of the 2 Billion Trees Program partners, big or small! This allows Indigenous communities and small businesses with specific forest restoration needs to reduce their costs and overcome technological obstacles. The NTSC can also act as a liaison to provincial seed centres involved in seed collection and the planting of non-traditional species – but which might be adequate for a given site – based on the best knowledge currently available.



Phytosanitary monitoring: from the nursery to the site

CFS researchers are working to develop molecular and sequencing tools to help in the early detection and identification of forest pathogens. Some pathogens can cause enormous losses in nurseries; this is the case with root rot. These physical seedling losses come at a heavy financial cost. Therefore, it is very important to detect these pathogens very early in the seedling production chain, well before the physical signs of the disease gain ground and the seedlings are sent to the planting sites. A variety of areas of expertise are needed to achieve this, such as epidemiology, pedology, forestry pathology, genomics and others.

Example of the use of an integrated approach for the planting of white pine

For a planting project where the main species to be reforested is white pine (a well-documented species), the integrated approach is particularly recommended. That said, the planting objective must be well defined along with the need that it will fulfill. To ensure the success of a planting project, the pathologies associated with this species must be known. This includes white pine blister rust, a fungus that attacks several species of pine. Checking the provenance of seeds, in an effort to limit the risk of seedling contamination, is also an essential step. Consultation with the nursery operator or seedling supplier ensures that the seedlings chosen are well adapted to the identified need and the site conditions. Provenance tests can guide professionals in this regard. Proper knowledge of the planting site and specifically the topography and soil conditions, including the water regime, will also help determine if white pine is indeed the right species to plant. And that's not it! White pine blister rust has a complex lifecycle. It requires an intermediary host to develop, such as the leaves of currants (*Ribes* spp.). Significant effort is needed to eliminate one of the disease's hosts using an adapted silvicultural treatment before planting. Even with these precautions, once the tree has been planted, monitoring is essential, both in terms of the pathogens and in terms of insects, including the white pine weevil. This is just one example among many illustrating the integrated approach for a planting project. Knowledge from the various disciplines such as pedology, pathology, entomology, ecology, silviculture and forest genomics must be considered at various stages of a tree's lifecycle.

Genetic diversity for climate change adaptation

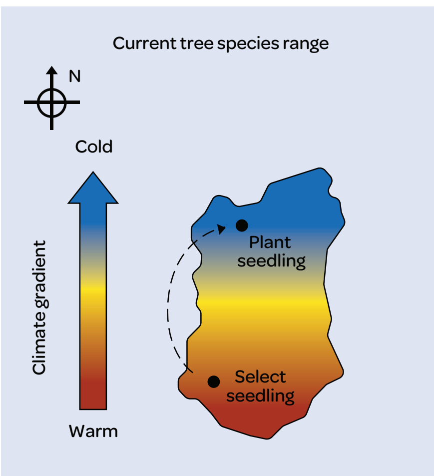
Within the context of a planting project, knowing how to select the right species and the right seeds for a specific location and climate is critical to the survival of trees. Generally speaking, native species are more likely to survive and develop properly. They also offer the greatest ecological benefit.

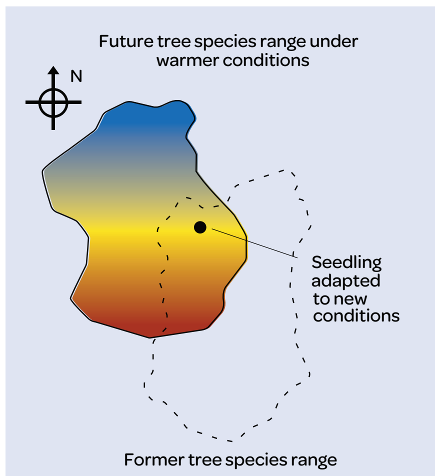
In the past, nursery operators generally used local tree seeds to produce seedlings, thinking that local populations were the best adapted to the site's climate conditions. However, that is no longer the case due to changing conditions and climate. Given the speed of changes observed, local populations may not be able to adapt quickly enough. Although well established, adult trees can generally withstand increased stress, seedlings are quite vulnerable. Determining geographic origin of genetic material, also known as provenance, is a crucial piece of information that must be taken into account.

Even though science is still grappling with this issue, there are tools already available to help make the right choice. One of these is Seedwhere. This tool makes it possible to map the climatic similarities between two geographic regions, such as those between a seed harvesting zone and a plantation site. Several analysis options are available and all of them may include climate change scenarios, making it possible to compare the current climate to future projected climates. Although it can be used for various purposes, the tool was initially designed to support seed relocation decisions as part of forest regeneration activities aimed at promoting sustainable forest management.

Indeed, individual trees from the same species can have genetic differences, which must be studied in the context of adaptation. For example, the populations of species growing at different altitudes can have genetic variations that are as pronounced as populations growing hundreds of kilometres apart. Similarly, certain tree populations of the same species from warm climates can grow longer and faster than populations from colder climates, although they may be less resistant to cold. The same species can adapt to different temperatures and soil moisture conditions from one region to another.

By determining the seeds and seedlings from the southern distribution area that prospered under changing conditions in the northern area, it becomes possible to strategically select trees that are more resistant and better adapted to the new environmental conditions.





Used alone, genomics does have its limits. By combining it with other approaches, such as dendroecology, it will be possible to select trees that are naturally better adapted to changing conditions in the area, while maintaining a balance with other important variables such as growth, wood density and survival rate.

The right species adapted to climate stressors

Under the effects of climate change, trees in Canadian forests will experience significant changes in their growing conditions and productivity. They will be faced with disturbances caused by fires or drought that will become more frequent, longer and more severe. Not all species will react in the same manner to these environmental changes as they continue to evolve.

Assessing the vulnerability of species to climate change requires information regarding three components: exposure, sensitivity and adaptability.

Exposure:
the scope of the environmental change, such as the temperature and precipitation regime to which a tree will be exposed.

Sensitivity:
the degree to which a species is likely to be affected or to react to an environmental change.

Adaptability:
the capacity of species to adapt or contend with environmental changes.

In terms of planting trees, tools for assessing their vulnerability to climate change could help in making good choices. Among other things, they would make it possible to select species with a greater tolerance to drought and a better capacity for reproduction after a period of drought. The notion of exposure involves, among other things, the concept of plant hardiness zones. As for the notions of sensitivity and adaptability, other tools are in the process of being developed and will soon be offered online.

Ongoing and future research

To find out more about genomics, the brochure on Forest Genomics published by the Canadian Forest Service presents various disciplines where this science can be used. It also describes national research projects conducted in collaboration with several institutions.

The research presented in this brochure will continue. Other research specifically related to the 2 Billion Trees Program will be initiated through partnerships with several academic, government and private organizations.

Advances in tree genomics now make it possible not only to strengthen existing tree populations, but also to prepare Canada's trees for new environments. CFS research in genomics and climate change aims to fulfill the need for knowledge regarding the 2 Billion Trees Program. This research will support the tree-planting program in order to maximize the impact and benefits in terms of reducing greenhouse gas emissions and other desired benefits such as increased biodiversity and the well-being of Canadians.