Canada's Country Report for The Second Report on the State of the World's Forest Genetic Resources:

SUBMITTED TO THE COMMISSION ON GENETIC RESOURCES FOR FOOD AND AGRICULTURE OF THE FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

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Preface

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Abbreviations and acronyms

2012 FGR Report: Report on the State of Canada's Forest Genetic Resources, 2012

AAC: annual allowable cut

ABS: access and benefit sharing

AdapTree: Genome Canada project (2011-2015), "Assessing the adaptive portfolio of reforestation stocks for future climates"

AFLP: amplified fragment length polymorphism genetic marker

BEC: Biogeoclimatic Ecosystem Classification system of British Columbia

CBST: climate-based seed transfer

CFGA: Canadian Forest Genetics Association

CONFORGEN: Conservation of Forest Genetic Resources group in Canada

COSEWIC: Committee on the Status of Endangered Wildlife in Canada.

EVOLTREE: European Union-funded network "Evolution of trees as drivers of terrestrial biodiversity"

FAO: Food and Agriculture Organization of the United Nations

FGC: Forest Genetics Council of British Columbia

FGCA: Forest Gene Conservation Association of Ontario

FGR: forest genetic resources

FGRM: Forest Genetic Resource Management program in Ontario

FIAS: forest invasive alien species

FLNRO: British Columbia Ministry of Forests, Lands, and Natural Resource Operations

FMA: Forest Management Agreement (an area-based form of forest tenure in some Canadian provinces)

GCTAC: Genetic Conservation Technical Advisory Committee of the Forest Genetics Council of British Columbia

GDP: gross domestic product

GMO: genetically modified organism

IUFRO: International Union of Forestry Organizations

ISSR: Inter-simple sequence repeat genetic marker

MTA: Material Transfer Agreement

NAFC: North American Forest Commission of the FAO

NAFGRWG (also called FGRWG): North American Forestry Commission's Working Group on Forest Genetic Resources

NRSA: Natural Resources Satellite Account (Statistics Canada)

NTFP: non-timber forest products

NTSC: Canada’s National Tree Seed Centre

OECD: Organisation for Economic Co-operation and Development

OMNRF: Ontario Ministry of Natural Resources and Forestry

OTIP: Operational Tree Improvement Program in British Columbia

RAPD: random amplification of polymorphic DNA genetic marker

RFLP: restriction fragment length polymorphism genetic marker

SARA: Canada’s Species at Risk Act

SE: somatic embryogenesis

SNP: single nucleotide polymorphism

TAC: Technical Advisory Committee of the Forest Genetics Council of British Columbia

Executive summary

Canada's forests cover 38% of its 9 million km^2 land area, totalling 347 million hectares and accounting for about 9% of the world's forest cover. Canada's over-all forest condition has not substantially changed since the 2012 Report on the State of Canada's Forest Genetic Resources (hereafter, "Canada's 2012 FGR Report"). Privately owned land accounts for about 6% of Canada's forests, 2% is owned by the federal government, 2% is Indigenous owned, and 90% falls under provincial and territorial jurisdiction. Provincial and territorial jurisdictions are responsible for management and conservation of natural resources, while the federal government has responsibility for representing Canada's forests on the international stage, regulating trade and commerce, managing national parks and lands used by the Department of Defence, and Indigenous lands. Both levels of government hold responsibility for the environment, with some areas of shared jurisdiction.

The Food and Agriculture Organization of the United Nations (FAO) considers forest genetic resources to represent "the heritable materials maintained within and among tree and other woody plant species (shrubs, palms and bamboo) that are of actual or potential economic, environmental, scientific or societal value". The present report focuses on the component of forest genetic resources represented by trees, while recognizing that all Canadian native tree and shrub species can be treated as forest genetic resources given their current or potential importance for ecosystem integrity and conservation values, wood or non-wood forest products, urban planting, ecological restoration, or for contributing to Canada's bioeconomy. More than 400 native tree and shrub species are found in Canada, of which 126 are trees (defined as reaching a height of at least 10m).

Currently, forest genetic resource valuation is most readily apparent in terms of overall forest qualities, combined with actual or prospective examples of resource development. In general, our forests provide recreational opportunities and spiritual benefits, habitat for large numbers of associated species, and they contribute to water quality and other ecosystem services. The main economic role of forests in Canada is supply of forest products. About 45 tree species are managed for commercial forestry. The total contribution of real GDP in 2012 dollars of the forest industry (logging, pulp and paper, and wood product manufacturing) rose from $18.8 billion in 2012 to $20.6 billion in 2018. Canada is the fourth largest forest product exporter in the world and leads in the export of softwood lumber and newsprint. Non-wood forest products such as maple syrup and Christmas trees, carbon sequestration, energy, and bioeconomy are locally important economic contributors. Canada's forests are also the second largest source of renewable energy after hydroelectricity. For example, forest biomass was the source of 85% of Canada's bioenergy in 2016, and between 2010 and 2016 the forest industry's fossil fuel greenhouse gas emissions decreased by 38% as a result of the use of forest-sourced bioenergy. Canada's emerging bioeconomy depends on the forest for biomass to produce bioplastics, biochemicals, and biofuels, and it is expected to grow rapidly.

Range-wide genetic data are lacking for most tree and shrub species in Canada, so existing estimates of genetic variation at the species level are often extrapolated from genetic research within a jurisdictional spatial scale, or are estimated based on surrogate measures such as population size or fragmentation. In Canada's 2012 FGR Report, jurisdictional assessments of *ex situ* genetic conservation needs along these lines resulted in 39 native Canadian tree species being categorised as requiring specific genetic conservation measures to preserve the integrity of their gene pools. Most of those species are hardwoods (33), five species are conifers from the genus *Pinus*, and the final species is the conifer *Juniperus maritima*. As of the present report, all 39 species are currently conserved as either seed lots or living *ex situ* accessions.

British Columbia, Alberta, and Ontario currently have strategies for forest genetic resources which include *in situ* conservation. Gap analyses carried out in British Columbia and Alberta have suggested that in British Columbia most tree forest genetic resources are adequately protected in the biogeoclimatic units in which they occur, while in Alberta protection appears adequate in the largest ecoregions (representing 65% of the province's area) but lacking for at least some species in smaller ecoregions.

There are four main *ex situ* conservation reserves for tree species in Canada: three jurisdictional seed banks (British Columbia, Alberta, Québec) and one federal Natural Resources Canada National Tree Seed Centre (NTSC). The majority of their efforts revolve around the collection, processing, testing and storage of seed sources from commercial species for reforestation. Currently, the NTSC has over 16,000 seed lots representing more than 120 species of native trees and shrubs, and it also manages representative seed samples from native trees and shrubs for conservation and research purposes. In 2019, the NTSC provided to domestic and international researchers over 6.5 million seeds from 520 source-identified and quality-tested seed lots, representing 60 tree species. Ultimately, the centre aims to store representative seed samples from across the natural ranges of all Canadian tree and shrub species.

Currently, the main use of tree forest genetic resources is in selective tree breeding (commonly referred to as "tree improvement") programmes, especially for qualities that enhance commercial forestry operations. Breeding for insect and disease resistance for species conservation is a growing but secondary goal. In British Columbia, 67% of the 300 million seedlings planted on public lands in 2020 were grown from this source. The proportion of selectively bred seeds is lower in other provinces, but nationally at least 50% of seed needs for reforestation are met by seed orchards, with the rest coming from wild stands. In Atlantic Canada, most seed requirements for several species are met with second generation orchard seeds. In Alberta, only about 15% of seeds are obtained from seed orchards, but the percentage increases annually as orchards mature and achieve higher production.

Most selective tree breeding is carried out using the classic methods for selection, seed orchard establishment and management, and controlled crosses. However, new technologies aimed at accelerating selection and breeding are gathering momentum. These include genomic analyses to develop marker-assisted selection for a broader assortment of traits than has been applied traditionally. A literature search revealed 40 articles published since Canada's 2012 FGR Report that describe genetic and genomic studies aimed at improved breeding and selection for 10 tree species, in particular white spruce (*Picea glauca*).

Promoting forest resilience to climate change must play an integral role in guiding stewardship of Canadian forest genetic resources. Climate change has strongly affected our forests and the forest sector via fire-, insect-, or pathogen-related impacts on plant health and forest ecosystem function. For example, although the total area of Canada's forested land burned by fire has not increased significantly over the past 20 years, several recent fires have occurred in locations where they were historically uncommon. As a case in point, large areas of pine that were killed by beetles in British Columbia as a result of climate change subsequently burned in 2018. The adoption by several provinces of a climate-based seed transfer approach is now providing a new level of complexity to tree breeding populations, seed orchard composition, and sourcing and deployment of seedlings. Besides these operational challenges, predicting future climate regimes and the tree traits that might best respond to those changes are areas of ongoing investigation. Breeding for multiple traits also poses the challenge of potential trade-offs between managing forests for overall resilience and promoting traits of importance to the forest industry.

Several related trends may enhance prospects for the conservation, sustainable use, and development of forest genetic resources in Canada. Consolidation of forest industry in recent years may improve prospects for effective forest management. Expanded forest protection is also anticipated, with a $1.3 billion federal investment announced in 2018 to enhance existing protected lands, including the use of forest inventory data. A federal "2 billion tree" initiative announced in 2019 offers additional opportunities for supporting selective tree breeding, particularly given the need for planting material that is adapted to future climates. In a related effort, the Canadian Forest Service has initiated a tree seed study headed by the National Tree Seed Centre in an assessment of future seed supply and demand. More generally, rapid advances in marker-assisted and genomic selection tools present valuable opportunities for advancing our understanding and use of forest genetic resources. This is most immediately apparent in terms of extending breeding programmes beyond traditional commercial selective tree breeding to applications such as land reclamation, ecosystem restoration, and climate-based seed transfer.

The Forest Genetic Resource Working Group (FGRWG) of the North American Forest Commission continues to benefit Canadian interests in forest genetic resource stewardship by promoting collaborative research and engagement between the United States, Mexico, and Canada. At a national level, The FGRWG delivers high quality science and science-to-policy tools, while also linking with national forest management agencies and contributing to the FAO's Global Plan of Action for the Conservation, Sustainable Management, and Development of Forest Genetic Resources. At a regional level, The FGRWG fosters dialogue and research at the North American scale encompassing many tree species' natural ranges. Its efforts along these lines raise awareness of the importance of forest genetic resources through training sessions, conferences, and publications.

Within Canada, the Canadian Forest Genetics Association (CFGA) is a network of forest genetics scientists and practitioners that promotes the use of scientifically and technically sound genetic practices in Canadian forestry activities, while the Conservation of Forest Genetic Resources group (CONFORGEN) promotes coordination and improvement in the stewardship of Canadian forest genetic resources in particular. CONFORGEN works to define and mainstream science-based guidelines for forest genetic resource monitoring and conservation. The group also identifies emerging issues and research priorities for genetic resource stewardship in collaboration with the FGRWG. Specific products delivered by CONFORGEN include conservation guidelines developed for seven tree species, a drafted scientific paper on *ex situ* conservation, approval of guidelines for *ex situ* conservation practices, and participation in the preparation of both Canada's 2012 FGR Report and the present report.

Needs identified within jurisdictions for effective FGR stewardship include: (1) identifying the genetic basis and potential adaptive responses of trees to climate change, and to insect and disease tolerance or resistance; (2) profiling population- and adaptive genetic characteristics of tree species needed for reforestation, restoration and land reclamation planting material; (3) establishment of a stronger forest health and resilience component within breeding programs to take full advantage of advanced generation breeding material, and; (4) promotion of increased awareness of the importance of forest genetic resources in forest resource management. Stable funding will be needed to support qualified personnel and materials in the activities above.

Chapter 1. Value and importance of forest genetic resources

Introduction

Canada, as the second largest country in the world with an area greater than 9 million km^2, accounts for about 9% of the world's forest, making it the third most forested country in the world. Forests cover 38% of Canada's land area, amounting to 347 million hectares (ha) and about 9% of that area is in legally protected areas. This means that there is about 10 ha of forest per Canadian (State of Canada's Forest 2020) and the forest has a special significance for Canadians. Forests have been a mainstay of Canada's economy for generations as a major contributor of jobs and income. The provision of recreational, restorative and spiritual values by Canada's forests has forged an ongoing connection with the Canadian psyche. Today, forests are also central to meeting Canada's climate change goals and are providing the fodder for the rapidly emerging bioeconomy.

Canada is a federation of 10 provinces and three territories ("jurisdictions"), which range in size from 5.6 thousand to 1.9 million km^2 (Figure 1.1). Canada's population is about 38 million (Statistics Canada, 2020) resulting in relatively low population density compared to most countries. The population is geographically concentrated however, with two-thirds of Canadians living within 100 km of the US border (Statistics Canada, 2020).

Only 6% of Canada's forest land (almost 400 million ha) is privately owned; 2% is owned by the federal government (national parks and Department of National Defence land); 2% is Indigenous owned, and; 90% falls under provincial and territorial jurisdiction (Natural Resources Canada, 2020). The different powers and responsibilities of provincial, territorial, and federal governments result in diverse land management policies and regulations across the country. Provincial and territorial jurisdictions are responsible for management and conservation of natural resources, while the federal government has responsibility for regulation of trade and commerce and Indigenous lands. Both levels of government have responsibility toward the environment with some areas of shared jurisdiction.

Canada's forested land has been classified as eight forest regions (Figure 1.2), and of these regions, the Boreal Forest is by far the largest, accounting for approximately 80% of Canada's forested area (Figure 2). The tree species found in the Boreal Forest Region typically have very broad distribution, ranging across several provinces and territories. Other forest regions contain tree species with much narrower distribution within Canada, but they may have large north-south distribution, ranging into the US. For example, the mountainous topography of British Columbia with its north-south orientation has four distinct forest regions hosting tree species that are not found in other parts of Canada. The number of tree species is inversely related to the size of the forest regions. The vast Boreal Forest contains a relatively low number of wide-spread species that are mainly wind-pollinated and exhibit high genetic diversity. The smallest forest region, the Carolinian Forest has the highest tree species diversity but some of the species, with limited distribution in Canada and shrinking habitat, have relatively low genetic diversity.

Figure 1.1. Political map of Canada.

About this report

This report builds on the previous report, submitted in 2012, hereafter referred to as "Canada's 2012 FGR Report". We note throughout this document where content from the 2012 report remains unchanged. A large volume of research carried out since 2012 contributes substantially to the understanding of forest tree genetic resources in terms of genetic diversity, genomic structure and function, and evolutionary processes. This report captures highlights of those research results, in addition to updating status and trend information.

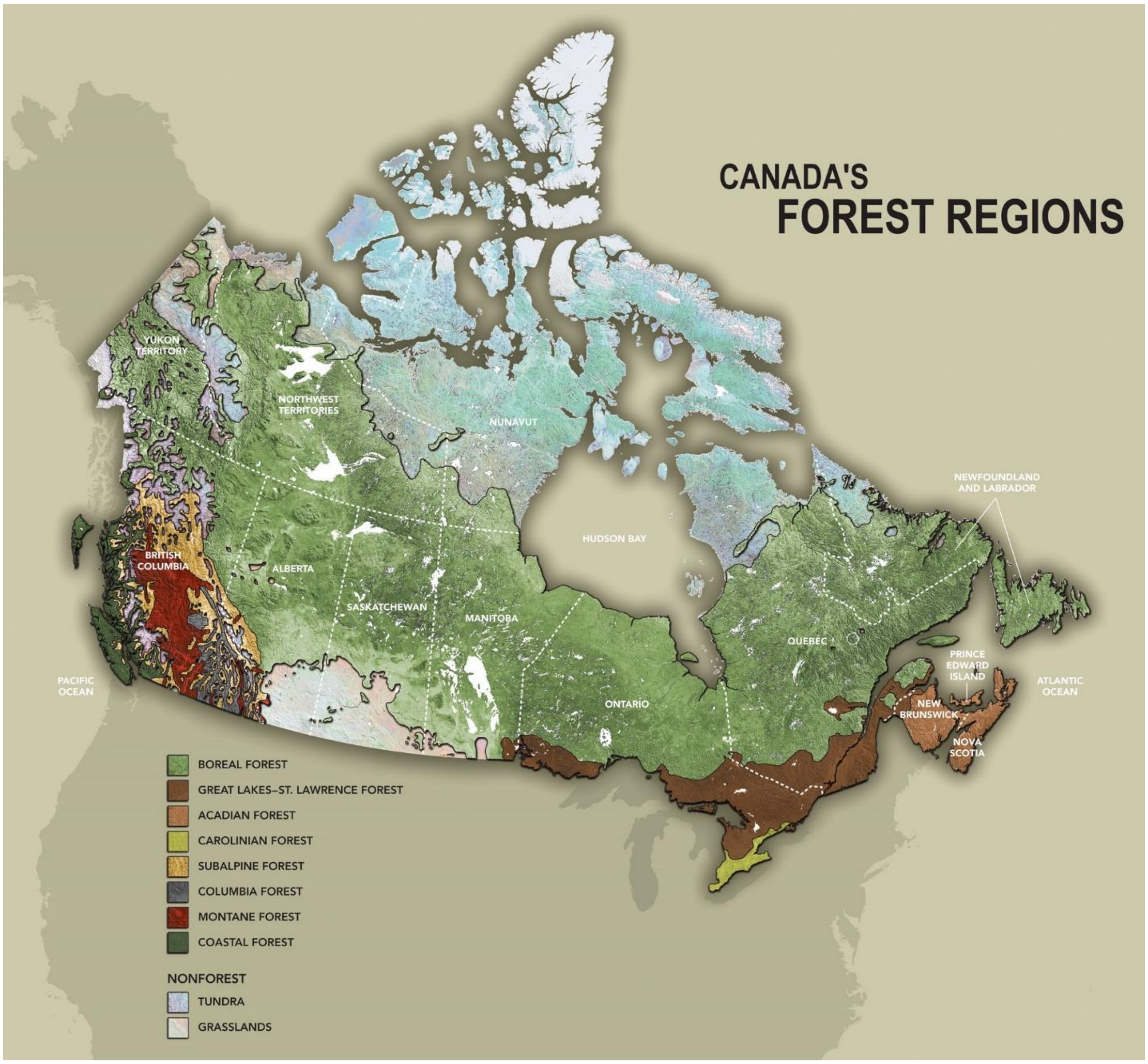

Figure 1.2. The forest regions of Canada (Natural Resources Canada)

1.1. The role of the forest sector in the national economy

According to data from Statistics Canada's Natural Resources Satellite Account (NRSA), the forest sector directly accounted for $27.6 billion of Canada's nominal GDP in 2017. The direct economic value of Canada's forest sector as a proportion of the nation's GDP has risen over the past 10 years. However, its exact value (1.4%) does not adequately reflect the great importance of the forest sector relative to other resource sectors. The forest sector creates more jobs and contributes more to the balance of trade for every dollar of value added than do other major sectors. The industry has a disproportionate value to rural areas and remote communities, supporting, with jobs and revenues, about 300 municipalities across the country. The forest industry provided employment for about 205,000 people across the country. This includes about 12,000 Indigenous people (State of Canada's Forests 2020b).

The total contribution of real GDP in 2012 dollars of the forest industry (logging, pulp and paper, and wood product manufacturing) rose from $18.8 billion in 2012 to $20.6 billion in 2018 and total revenue from goods manufactured was more than $77 billion in 2018 (Table 1.1).

Table 1.1. The role of the forest sector in the national economy.

Year	2012	2013	2014	2015	2016	2017	2018
Contribution to nominal GDP (current dollars)							
Forestry and logging industry	3,937,000,000	3,391,000,000	3,728,000,000	3,985,000,000	4,086,000,000	4,161,000,067	4,614,818,030
Pulp and paper product manufacturing industry	7,466,000,000	7,419,000,000	7,927,000,000	8,581,000,000	8,607,000,000	9,115,046,993	10,046,855,544
Wood product manufacturing industry	7,402,000,000	8,785,000,000	8,724,000,000	8,961,000,000	9,990,000,000	10,841,224,359	11,350,675,885
Total contribution to nominal GDP	18,805,000,000	19,595,000,000	20,397,000,000	21,527,000,000	22,683,000,000	24,117,271,419	26,012,349,459
Contribution to real GDP (constant 2012 dollars)							
Forestry and logging industry	3,937,000,000	4,049,000,000	4,210,000,000	4,259,000,000	4,030,000,000	3,939,000,000	3,985,000,000
Pulp and paper product manufacturing industry	7,466,000,000	7,146,000,000	7,547,000,000	7,857,000,000	7,647,000,000	7,690,000,000	7,604,000,000
Wood product manufacturing industry	7,402,000,000	7,928,000,000	8,124,000,000	8,394,000,000	8,872,000,000	9,138,000,000	8,971,000,000
Total contribution to real GDP	18,805,000,000	19,123,000,000	19,881,000,000	20,510,000,000	20,549,000,000	20,767,000,000	20,560,000,000
Revenue from goods manufactured (dollars)							

Year	2012	2013	2014	2015	2016	2017	2018
Logging industry	8,565,752,000	8,928,442,000	9,199,638,000	9,381,792,000	9,782,530,000	10,154,358,000	10,806,584,000
Pulp and paper product manufacturing industry	23,245,171,000	23,165,414,000	25,352,934,000	25,861,315,000	25,684,269,000	27, 736,303,000	30,592,308,000
Converted paper product manufacturing	7,883,666,000	8,686,178,000	10,249,217,000	9,807,737,000	9,839,123,000	10,580,368,000	11,027,162,000
Pulp, paper and paperboard mills	15,361,505,000	14,479,236,000	15,103,717,000	16,053,578,000	15, 845,146,000	17,155,935,000	19,565,146,000
Wood product manufacturing industry	21,328,395,000	25,207,657,000	26,409,948,000	27,415,986,000	29, 772,070,000	33,355,765,000	35,814,788,000
Other wood product manufacturing	6,743,430,000	7,361,273,000	7,478,184,000	7,689,949,000	7, 988,203,000	8,409,112,000	9,141,275,000
Sawmills and wood preservation	9,997,182,000	12,481,878,000	13,629,903,000	14,117,417,000	15, 248,737,000	17,251,956,000	18,403,500,000
Veneer, plywood and engineered wood product manufacturing	4,587,783,000	5,364,507,000	5,301,862,000	5,608,621,000	6, 535,130,000	7,694,697,000	8,270,013,000
Total revenue from goods manufactured	53,139,318,000	57,301,513,000	60,962,520,000	62,659,093,000	65,238,869,000	71,246,426,000	77,213,680,000

https://cfs.nrcan.gc.ca/statsprofile/economicimpact/ca

Many non-timber forest products are harvested and sold in Canada, including traditional ones such as decorative boughs, berries, mushrooms, fiddleheads, Christmas trees and maple syrup; and new ones based on extractives and bioproducts. In spite of the local economic importance and the social and cultural significance of non-timber forest products, harvest or sales data are not collected for most of them. The annual quantity and value of maple products is tracked, however (Table 1.2), as well as some Christmas tree data. The area of Christmas tree farms was only available for 2016 and dollar value was available only in 2017.

Table 1.2. The two major non-timber forest products.

Year	Maple products		Christmas trees	
	Litres (millions)	**Value ($ millions)**	**Number of hectares**	**Value ($ millions)**
2012	29.73	305.543		
2013	38.05	409.661		
2014	35.90	381.222		
2015	33.72	358.242		
2016	46.03	484.109	23,787	
2017	47.36	493.992		91.2
2018	37.08	385.531		
2019	49.98	517.489		

Statistics Canada. Table 32-10-0354-01 Production and value of maple products (x 1,000), https://doi.org/10.25318/3210035401-eng; Statistics Canada. Table 32-10-0421-01 Christmas trees, https://doi.org/10.25318/3210042101-eng

Canada's emerging bioeconomy depends on the forest for biomass to produce bioplastics, biochemicals and biofuels (Natural Resources Canada 2020). Forest industry is actively finding new ways to use forest biomass both to offset greenhouse gas emissions and to add value to the Canadian economy. One product that has strong potential is transparent wood made from lignin, stronger than glass and with a higher insulation factor. Lignin can also be used to make a strong, light-weight foam. Wood waste is being used for making bioplastic for 3-D printers.

Canada's forests are the second largest source of renewable energy after hydroelectricity. Forest biomass was the source of 85% of Canada's bioenergy in 2016, and between 2010 and 2016 the forest industry's fossil fuel greenhouse gas emissions went down by 38% because of using forest-sourced bioenergy (Natural Resources Canada 2020).

Forest sales contribute significantly to provincial sales revenues.

Table 1.3. Provincial forest sales (stumpage, rents, reforestation fees, protection fees, licences).

Year	Value ($ millions)
2013	1147.396
2014	1215.916
2015	1345.631
2016	1441.553
2017	1539.243

Statistics Canada, 2018

1.2. The main roles of forests in Canada (supply of wood and non-wood products, provisioning of ecosystem services)

The main economic role of forests in Canada is supply of forest products. Non-wood forest products such as maple syrup and Christmas trees; carbon sequestration, energy, and bioeconomy are locally important economic contributors. The bioeconomy is expected to grow rapidly; Canada's first bioeconomy strategy was released in 2019 (Bioindustrial Innovation Canada, 2018). Canada's forests provide recreational opportunities and spiritual values for many Canadians, as well as habitat for large numbers of associated species, contribute to water quality and other ecosystem services.

1.3. Specific economic, environmental, social and cultural values of forest genetic resources

Forest genetic resources (FGR) are defined by the FAO as "the heritable materials within and among tree species and other woody plants. FGR underpin the adaptive potential that has enabled trees to be, in evolutionary terms, among the planet's most successful types of organism." For the purposes of this report, FGR are taken to refer to genetic resources of trees, although it is recognised that many other classes of organisms are components of forest ecosystems.

The actual and potential value of the genetic diversity in trees that is required for breeding, for resistance to insects or diseases, or for tolerance to climate extremes is significant from economic, environmental, and socio-cultural perspectives. The specific value of FGR across Canada as a whole has not been calculated or explicitly considered at the federal level. However, provincial representatives have provided information on the value of FGR from jurisdictional perspectives.

British Columbia

In British Columbia, FGR are managed for each of four values:

1) Economic: some 250-300 million trees are planted annually in British Columbia, representing significant costs and benefits to the people of BC, and adding value in comparison with natural regeneration, in terms of growth, adaptation, and disease and insect resistance.

2) Environmental: ecosystem services such as water quality, wildlife habitat, and wood products. More than 12 tree species are planted across the British Columbia landscape, usually in mixtures corresponding to conditions where they naturally occurred with respect to the province's ecological zonation.

3) Scientific: the best available scientific technology is used in tree breeding and genetic conservation to advance genetic resource management of tree populations, while employing the latest science in assisted migration in response to climate change. BC is one of the first forestry organizations to apply climate-based seed transfer zones (CBST).

4) Social and cultural values: forestry in BC has been the economic engine for over 120 years so it features strongly in provincial politics and public opinion. Indigenous peoples have increasing roles in forestry.

In recent years, climate change has been accompanied by more wildfires, insect outbreaks, and drought in BC, challenging the forest industry and its role as the most valuable natural resource in the province. In light of these challenges, the chief forester of BC views proper management of FGR to be a key issue.

Alberta

The government of Alberta has appraised FGR in terms of three categories:

1) Economic: Alberta's forest industry, mainly primary products manufacturing and export, directly employs 18,700 Albertans and 25,300 people in supporting occupations. Industry revenues exceed CAD $6.5 billion from harvesting operations and sales. Selective tree breeding (commonly referred to as "tree improvement") is recognized as a priority of both government and industry to support the forest sector. Genetic resources are recognized as key to healthy, well-adapted, genetically diverse forests that can sustain multiple values.

2) Environmental: Diversity is a core environmental value supported by Alberta's FGR management. Minimum diversity levels must be met for seedlot registration, which is mandatory prior to use. Deployment is also linked to genetic diversity levels, where seedlots having higher effective population sizes are allowed greater deployment.

3) Social and cultural: FGR management is rarely an explicit goal in protected areas of Alberta but parks and Provincial Recreation Areas have high recreational and public amenity value. Some visitors value species diversity, noting differences with changing seasons, or recreational value in different forest types, but most value access to nature and may not focus on specific genetic or diversity attributes. Indigenous cultures in Alberta place a very high value on specific species as well as certain areas with spiritual value. Traditional places for gathering plant materials are often in forests, which may be in provincially administered public lands or in federally administered reserve lands. Indigenous peoples in Alberta have collaborated with the provincial government in support of "Genetic conservation of the endangered limber and whitebark pine" program.

Wildcrafting and foraging are also cultural uses of forest products in Alberta, but there is little data on their extent. Willow furniture, woodworking, cosmetics, natural fibres, and edibles are all growing sectors. "Forest bathing" is a global trend that is supported by growing body of literature confirming the cultural and wellness benefits of spending time in nature. These cultural values may not specifically address genetics, but may present some opportunities for selective breeding or seed production programs should the demand for forest bathing support it.

Although not noted by the provincial representative, there is a flourishing research program on various aspects of FGR involving the Alberta provincial government, industry, and academia (especially the University of Alberta).

Ontario

The government of Ontario recognizes FGR values as follows:

1) Economic: Selective breeding programs for black and white spruce (*Picea mariana*, *Picea glauca*), and for jack and white pine (*Pinus banksiana*, *Pinus strobus*) are focused on enhancing forest health, productivity, and wood quality. Conserving broad intraspecific genetic variation maximizes the potential for conserving adaptive genetic variation suitable for new conditions resulting from climate change. A new policy under development that reflects this priority is aimed at customising seed transfer for tree species important for reforestation in a manner that matches source material with climatic conditions.

2) Environmental: Genetic resistance of threatened tree species to insects and diseases is being explored and used where available for species recovery and wildlife habitat enhancement. Focal species include butternut, ash, beech, eastern white pine, chestnut. Another example of explicit recognition of FGR values is in seed source selection for urban planting.

3) Social and Cultural Values: These specific FGR values are reflected in the efforts towards recovery of threatened or endangered keystone tree species including American chestnut (*Castanea dentate)*, butternut (*Juglans cinerea*), eastern white pine (*Pinus strobus*), American beech (*Fagus grandifolia*), and American elm (*Ulmus americana*). Collaborative efforts involve the Ontario government, Indigenous peoples, universities, conservation organisations, and private citizens.

Quebec

In Quebec, the economic and environmental values of FGR are recognized through the many efforts undertaken to use and conserve genetic diversity:

1) Economic: many tree breeding programs have been developed over the last 50 years in Quebec to provide selectively bred and locally adapted seedlings for reforestation. More than 125 million trees are planted annually, and are of high economic value for the Quebec forest sector. Genetic diversity is a priority of Quebec tree breeding programs, both for the sake of selected material for and avoidance of inbreeding.

2) Environmental: Several conservation areas have been established in diverse ecosystems across Quebec over the last 30 to 40 years, collectively contributing to forest biodiversity *in situ* and to supplying environmental, scientific, and societal value. Although the objective of these areas is not explicitly to conserve FGR, genetic diversity is recognized as a value within these protected areas.

An active collaborative research program involving Laval University, the Canadian Forest Service, and the provincial government has advanced understanding and contributed to the realized value of FGR in recent years (e.g., Chamberland *et al.* 2020).

1) Economic: The most obvious value of the selective tree breeding program is associated with the genetic gain (increased performance) that has been achieved. In economic terms, the improvement in both quality and quantity of available wood has been notable.

2) Environmental: The province subscribes to the triad approach to forest management, whereby intensive management of productive forest (including selective tree breeding) meets wood product needs on smaller plantation areas, which allows for more natural forest and protected forest areas. Also, by selecting plus-trees from across the Maritime provinces and in the US state of Maine, the genetic diversity of the plantations that are being established now has increased in comparison with wild seed collections.

Atlantic Canada

Atlantic Canada has had an active tree breeding programme for 40 years, during which at least 750 million selectively bred seedlings have been planted in the region, covering approximately 340,000 ha. In one of the only existing attempts to estimate an economic value associated with specific genetic resources, Adams (2020) estimated the gain of more than seven million cubic metres of wood resulting from this reforestation effort, with a stumpage value at $15/m^3 was valued at more than $100 million.

1.4. Contributions of forest genetic resources to sustainable development

In British Columbia, genetic resources contribute to sustainable development[1] by improving growth performance and adaptation related to climate tolerance and pest resistance for the 300,000,000+ trees that are being planted annually. These enhanced growth and adaptation traits are factored into growth models to establish future cutting levels. Provincial government actors recognize the importance of forest products to the economy, but they also recognize that, in the future, having healthy and well-established plantations, with the appropriate germplasm, will be as important. With the increasing losses due to fires and insect damage in recent years, reforestation efforts using genetically appropriate stock are increasing.

In Alberta, as in New Brunswick, there is a perception that as yield increases due to selective tree breeding, harvest rates will increase without expanding the industrial footprint. Selective breeding that translates into rapid early growth provides opportunities to reduce stand establishment costs and inputs such as chemical and mechanical competition control.

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[1] The concept of sustainable development was described by the 1987 Bruntland Commission Report as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." There are four dimensions to sustainable development – society, environment, culture and economy – which are intertwined, not separate.
https://en.unesco.org/themes/education-sustainable-development/what-is-esd/sd

Recent changes to Alberta's building codes demonstrate that there is a great opportunity for increasing the use of low-carbon and renewable building materials. Most mills now have some cogeneration capacity to meet the increasing demand for biomass for energy. Biogasification is under development at several landfills to capture methane and produce energy. The value-added products such as finger joining, veneer, finishing products, and trusses that are produced by smaller mills, as well as fibre with specific properties such as dissolving pulp or long fibres that increase recycling potential, are in growing demand. The growth of all of these sustainable industries can be supported by increasing the level of deployment of orchard seed with higher genetic gain, and also increasing capacity for selection and breeding for industry-specific traits.

A significant proportion of Ontario's managed forest is regenerated with selectively bred seed produced through Ontario's Forest Genetic Resource Management (FGRM) programs leading to a number of contributions to sustainable development. From an economic perspective, the selectively bred material contributes to greater harvested wood volume with its proportional contribution to the country's GDP, job creation, international trade and development in northern Ontario. The increased productivity of plantations, as a result of selective tree breeding, allows for environmental protection in natural forests. Renewable energy in the form of wood pellets can help mitigate climate change through enhanced carbon sequestration with more rapidly growing plantation trees and enhanced wood volume for construction.

In Quebec, as elsewhere, consideration of FGR forms the basis of all tree breeding programs, seed orchards and seed production areas, and contributes to all selectively bred seedlings currently used in reforestation programs in Quebec. Meeting the first goal of reforestation programs, which is to assure adequate regeneration using suitable genetic material (where natural regeneration is lacking after harvest) is a direct contribution to sustainable development. A second goal is indirect: to assure that the deployment of intensive forestry occurs on a small part of the provincial land in different regions of Quebec near villages and towns in order to decrease harvesting pressures on natural forests. Pursuing this goal has involved following the principle that the higher the genetic gain in deployed material, the smaller the area of intensive forestry is required for a given yield of forest products.

In New Brunswick, managers of government land are starting to reap the economic benefits of high-quality trees with less branching, improved form, and faster growth. Consequently, more wood can be harvested from a given area in a shorter rotation period than was possible prior to the deployment of selectively bred seedlings. The investment in seed orchards ensures a steady supply of high-quality seed.

1.5. Priorities to enhance FGR contributions to sustainable development

Priorities across the country include:

1) building a stronger forest health component into breeding programs to take full advantage of advanced generation breeding material;
2) increasing gain in productivity without detrimentally affecting local adaptation;

3) developing and deploying new seed zones and transfer rules in response to climate change (BC is rapidly moving to a climate based seed transfer (CBST) system);
4) enhancing selective tree breeding programs for promising species;
5) *ex situ* conservation of genetic resources by maintaining provenance and progeny trials; and,
6) inventory of FGR.

As a step toward these priorities, Alberta has a formalized system for setting priorities with clients, and has to balance economic development with its stewardship mandate (guided by regulations in the provincial standards).

The greatest need identified by all jurisdictions is for increased internal capacity and stable funding. The difficulty in replacing geneticists, tree breeders, and other selective breeding program staff has been emphasized. Annual funding fluctuations do not reliably support the long-term planning that is needed for adequate development and maintenance of FGR programs. Improved collaboration was also identified as a need in one jurisdiction, which noted that more research collaboration between government and universities is needed, as well as continued improvement in collaboration between government departments.

1.6. The perception of different stakeholders on the importance of forest genetic resources

Forest industry in all jurisdictions has responsibility for reforesting after harvesting. Availability of adequate supplies of good quality seed is recognized as a high priority and most produce or seek selectively bred material. To varying degrees, industry tends to view establishing fast-growing trees on harvested land as important and selective tree breeding as vital to achieving this objective. Provincial and federal government departments broadly recognize the value of genetic diversity, both as a source of sustainable economic growth through selective breeding and genomic initiatives and as a resource for forest conservation.

Numerous universities are involved in research and training on FGR, with increasing collaboration with provincial programs. In general, academia advances fundamental research and approaches that find their way into genetic resource management and breeding programs at later points, such as through genomic tools to aid in selection or through insights for optimizing seed transfer under changing climatic norms.

Non-government organizations recognize and value genetic resources to varying degrees. While some with specific threatened species mandates have a high awareness of the value of genetic resources (e.g., the Whitebark Pine Ecosystem Foundation of Canada, and the Forest Gene Conservation Association in Ontario), others with a broader mandate do not explicitly recognise genetic values.

1.7. Constraints to increasing awareness on the value of forest genetic resources

The biggest constraint to increasing awareness of the value and importance of FGR is lack of financial resources, leading to reduced funding and staff. In British Columbia, the provincial

Forest Genetics Program has received strong support from industry and government for about 60 years. There is also support in that province from the general public for FGR management. In Quebec, in spite of diminishing provincial resources for staffing in genetic programs, the importance of FGR has been taught over the last 20 years at the University of Laval to all future professional foresters, as part of a mandatory course related to breeding, reforestation, and silviculture issues. This contributes to greater awareness among younger foresters. Increasingly, FGR is also considered as a criterion by forest ecologists to establish new conservation areas. However, these advances stand out from the generally modest support for genetic resource management. In other jurisdictions across Canada, diminishing programs or numbers of professionals working on FGR lack the required funds for outreach or scientific collaboration.

Literature Cited

Adams, G. 2020. Tree improvement in Atlantic Canada – Over 40 years and going strong. Tree Seed Working Group News Bulletin, Canadian Forest Genetics Association. No. 69. p. 28-29.

Bioindustrial Innovation Canada. 2018. Canada's Bioeconomy Strategy: Leveraging our Strengths for a Sustainable Future. Agriculture and Agri-Food Canada. 68 pp. https://www.bincanada.ca/biodesign accessed April 2020

Chamberland, V., Robichaud, F., Perron, M., Gélinas, N., Bousquet, J. and Beaulieu, J., 2020. Conventional versus genomic selection for white spruce improvement: a comparison of costs and benefits of plantations on Quebec public lands. Tree Genetics & Genomes, 16(1), pp.1-16.Natural Resources Canada. 2020a. Forest land ownership. https://www.nrcan.gc.ca/our-natural-resources/forests-forestry/sustainable-forest-management/forest-land-ownership/17495 Accessed April 2020

Natural Resources Canada. 2020b. How does the forest industry contribute to Canada's economy? https://www.nrcan.gc.ca/our-natural-resources/forests-forestry/state-canadas-forests-report/forest-industry-contribute/16517 Accessed April 2020

Statistics Canada. 2020. Population and demography statistics. https://www.statcan.gc.ca/eng/subjects-start/population_and_demography Accessed April 2020

Statistics Canada. 2018. Logging, 2018. https://www150.statcan.gc.ca/n1/en/daily-quotidien/191223/dq191223e-eng.pdf?st=NIV_k-2W Accessed April 2020

Chapter 2. State of diversity in forests

2.1 State of Canada's forests

Canada's over-all forest condition has not substantially changed since 2012 (Table 2.1). Canada's forest and other wooded land comprises 44% of the country's land base. The area that is deforested annually is very small, accounting for 0.01% of the forest area in 2017, the most significant causes of deforestation were mining, oil exploration, and agriculture. Forest harvesting is not counted as deforestation, given that regeneration is considere d a part of the forest management cycle. Although afforestation occurs, the area that is planted annually is small enough that it is not systemically tracked.

Canada's forest tree species richness is moderate, but the evenness diversity measure is very low, with vast tracts of land covered by one or two tree species. The predominant tree genera in Canada's forests, presented in Table 2.1, are softwoods (almost 80% by volume) and five species of the spruce genus (*Picea*) account for almost 50% of that volume. The most species-diverse ecosystems are in southern Ontario where "other hardwoods" account for 0.5% of the total volume of Canada's standing forest.

Table 2.1. Overview of Canada's forest condition (From Natural Resources Canada 2020 and https://cfs.nrcan.gc.ca/statsprofile/overview/ca).

Forest and other wooded land by classification	**Hectares (2017)**
Forest land	347,039,050
Other wooded land[1]	40,865,660
Other land with tree cover[2]	8,498,940
Forest area change	**Hectares (2017)**
Afforestation	Insignificant
Deforestation	35,386
Forest type (forest land only)	**Percentage**
Coniferous	67.8%
Mixedwood	15.8%
Broadleaf	10.5%
Temporarily non-treed	5.9%
Forest ownership	**Percentage**
Provincial	76.6%
Territorial	12.9%
Private	6.2%
Aboriginal	2.0%
Federal	1.6%
Municipal	0.3%
Other	0.4%
Growing stock	**Million cubic metres**
Total volume	47,320

Predominant tree genus (forest land only)	Percentage by volume
Spruce	47.3%
Pine	11.9%
Fir	7.4%
Hemlock	5.8%
Douglas-fir	3.5%
Larch	0.6%
Cedar and other conifers	2.7%
Unspecified conifers	0.7%
Poplar	13.1%
Birch	3.3%
Maple	3.0%
Other hardwoods	0.5%
Unspecified hardwoods	0.2%
Unclassified	0.1%
Land use	**Thousand hectares**
Agriculture	62,154.3
Conservation	83,508.9
Forestry	258,604.3
Industrial	472.8
Infrastructure	8,051.9
National Defence	2,314.1
Recreation	70,443.7
Settlement	4,453.0
Unknown	158,350.7
Total	648,353.6

1. “Other wooded land” follows the FAO definition of land where tree canopies cover 5% - 10% of the total area and the trees, when mature, can grow to a height above 5m, or shrubs, bushes and trees together cover more than 10% of the area (treed wetlands and land with slow-growing, scattered trees).
2. “Other land with tree cover” follows the FAO definition of land where tree canopies cover more than 10% of the total area and trees, when mature, can grow to a height of at least 5m (treed areas on farms, orchards, parks and gardens) from FAO

Canada reports on sustainability indicators in line with the Montreal Process, which are also used to report progress toward United Nations Sustainable Development Goals. The sustainability indicators are used domestically for three purposes (Natural Resources Canada, 2020):

1. provide essential information about the state of and trends in Canada’s forests;
2. highlight needs for selective tree breeding in sustainable forest management practices and policies; and,

3. supply reliable information for discussions and initiatives related to environmental performance and trade.

Indicators measured in Canada are listed in Table 2.2 along with a brief summary of their current status. The first 12 indicators provide information about the forest and environmental sustainability. The remaining nine indicators pertain to the sustainability of the forest industry from an economic and social perspective.

Table 2.2 Canada's Sustainability Indicators and brief descriptions of status.

Indicator	Status
Environmental	
Forest Area	From 1990 to 2018, less than half of 1% of forest area was lost, with greatest area reduction in the Prairie Ecoregion (6.5% loss), the Mixedwood Plains (2% loss) and Boreal Plains (1.5% loss). Most of the area lost was converted to agriculture.
Deforestation and afforestation	Canada's deforestation rate is very low and declining. From 1990 to 2017 annual deforestation declined from 64,000 ha to 35,000 ha. Afforestation occurs at a very low level relative to forest area.
Wood volume	Over the period 1990 – 2016 wood volume declined from 47,625.38 to 45,107.59 million cubic metres mainly because of the impact of natural disturbances. During this period, the area of forest affected by fire and insects was 20 times greater than the area affected by harvesting and deforestation.
Forest area within protected areas	The area has more than doubled since 1990 from 13,546.00 to 29,507.00 thousand hectares; 8.5% of Canada's forest is within protected areas. In 2018, the government of Canada announced $1.3 billion to expand the extent of protected areas and to enhance existing ones, including the use of forest inventory data to characterize the protected forests.
Area harvested	In 2017, approximately 756,000 ha of forest were harvested, down 1.9% from 2016 and down 24% from the average area harvested from 1995-2005. The decline is largely due to increased area of forest damaged by insects (mountain pine beetle) and fires. The area harvested annually is less than half of 1% of the total forest area.
Regeneration	Successful regeneration is required for Crown land harvest licenses; more than 50% of the harvested area has been artificially regenerated over the past 20 years. In 2017, 572 million seedlings were planted on 396,000 ha. Both number of seedlings planted and area planted in 2017 were at least 6% higher than the 10-year average.
Volume harvested relative to the sustainable wood supply	The 2017 sustainable wood supply is calculated to be 219.6 million m^3, down from 2016 by 3.5 million m^3. The harvest in 2017, 155.2 m^3, is well below the sustainable harvest.

Indicator	Status
Forest area with long-term management plans	More than half (57.6%) of Canada's forest land has a long-term (10 year or longer) management plan, including areas managed for timber production and protected areas, representing an increase of 8% since 1990. The development of management plans follows a strict process, in most cases requiring input from forest industry, government agencies, Indigenous peoples, the public, and other stakeholders.
Forest insects	Insect or pathogens are second only to forest fire as an impact on Canada's forests. Insects affected 15.6 million ha of forest land in 2017, which is within 1% of the previous year. Spruce budworm in Quebec was the most important insect or pathogen in terms of area affected. Mountain pine beetle was at its lowest point in 10 years in 2017.
Forest diseases	Forest managers manage disease through tree breeding and silviculture in order to reduce impacts. Forest pathogens reduce growth and decrease productivity but the severity and area of damage in Canada's forests has not been estimated. Abiotic factors, including those associated with changing climate, affect the severity of pathogens.
Forest fires	More than 7000 forest fires burned almost 2.3 million ha of forest in 2018 which is close to the 20 year average, but serious fires occurred in unusual places such as Vancouver Island. Forest fires in mainland British Columbia occurred in extensive areas of pine that were killed during the past decade by the mountain pine beetle.
Carbon emissions and removals	Canada's forests had an estimated net emission of about 217 million tonnes of carbon in 2017. Forest management and use of wood products constitute a sink amounting to about 20 million tonnes of CO_2. An area totalling about 1.5 million ha of managed forest land was burned by wildfires in 2017, increasing the net CO_2 emission rate.
Social & Economic	
Employment	Canada's forest sector employed 210,615 people in 2018; a slight decline from 2017. The pulp and paper industry faced a continuing decline in demand for paper products and the wood product manufacturing industries experienced a decline in prices for wood products. These two factors contributed to a reduction in employment, but the employment numbers were increased in fire management related activities.
Average earnings	Average earnings in the forest sector are down by 3.9% in 2018 compared with 2017 but are still higher than the average earnings across the total manufacturing sector.
Communities	About 31% of Canadians, including about 70% of Indigenous people, live in or near forests. About 300 communities, including 2% of Canada's population, are reliant on the forest sector for jobs and income. Many less easily measured benefits also flow from the forest to those who live in proximity.

Indicator	Status
Gross domestic product	Canada's nominal gross domestic product included $25.8 billion (1.2%) contributed by the forest industry in 2018. The GDP contributed by the forest industry declined by 1% from the previous year, while the overall economy increased by 2.3%. The decline in the forest industry contribution was mainly due to weak demand for both wood and paper products.
Production	Forest production has remained approximately constant over the past 10 years except for a growth in structural wood panel production. Canada is the world's largest producer of newsprint but the demand for that product is shrinking worldwide.
Exports	Forest product exports from Canada are up for the sixth consecutive year, with the total export value growing by 53% between 2012 and 2018. Pulp and printing and writing paper value rose between 17 and 18% from 2017 to 2018, because of higher prices. Canada is the fourth largest forest product exporter in the world and leads in export of softwood lumber and newsprint.
Financial performance	Performance improved for the 7th consecutive year with increased operating profits and increased return on capital expenditures, indicating a highly competitive forest industry.
Secondary manufacturing	Real GDP from secondary manufacturing decreased by 11% from 2008 to 2018. It accounted for 35% of the total contribution of forest product manufacturing in 2018.
Forest industry carbon emissions	Total greenhouse gas emissions in the forest industry from fossil fuel use have declined by 38% over the past 10 years, while energy use has remained stable over the same period. The reduction is largely due to generation of electricity from bioenergy.

Two new indicators were added in 2019: "Forest area within protected areas" and "Forest area with long term management plans". Both are relevant to the status of forest genetic resources (FGR); although protected areas are not designed specifically to conserve genetic resources, they are recognised as important potential sources of forest genetic diversity. Although the value of protected areas specifically for forest tree genetic conservation has been questioned, there is a common recognition that extensive undisturbed natural habitat is required to maintain tree populations that allow for adaptive evolution with respect to climate change. The requirement for a long-term management plan for protected areas is particularly important for managing FGRs, because current management decisions have long implications for forest genetic diversity. In the absence of long-term planning for forest genetic diversity, adequate management is likely to be piecemeal and incidental, resulting in inadequate protection of FGRs in general. Management of protected areas has increased substantially over the past 30 years, although no formal mechanism for protecting FGRs currently exists.

2.2. Trends affecting forests and their management

Ongoing climate change and associated changes in fire regimes, and insect or pathogen damage encompass the most significant trends affecting forest resources. In British Columbia, for example, three of the 10 largest fires in a century have occurred in the last six years (Natural Resources Canada 2020). Analysis of historical climate data collected in British Columbia reveals numerous changes currently affecting terrestrial ecosystems that are relevant to fire regimes (British Columbia Ministry of Environment, 2016). Between 1900 and 2013, the average annual temperature across British Columbia rose by 1.4°C, with northern regions warming more than the average. Notably, the nighttime minimum average temperature over the same period increased by 3.1°C and precipitation has increased at the same time. Both fire activity and insects or pathogens can accelerate in the presence of increased heat energy, with insect or pathogen effects potentially further exacerbated by drought stress experienced by trees in the presence of increased ambient temperature. These effects interact with precipitation but data are lacking on the relationship of this regionally variable factor to fire and insect or pathogen activity.

Wood supply is estimated as the sum of the annual allowable cut (AAC) calculations for managed forest land in all provincial, territorial and federal jurisdictions. Forest removed from commercial operations for park establishment influence wood supply, as do fire impacts and insect or pathogens. But wood supply, and net forest harvest (a proportion of the AAC), fluctuates primarily in response to markets. Industry innovation, including capitalizing on the emerging bioeconomy, has in recent years resulted in decreased forest harvest demand across Canada. This trend has been driven by a reduction in demand for newsprint and soft lumber markets, along with a transition to a less carbon-dependent economy in general. Wood supply has decreased since 2009, after having previously remained relatively constant for almost 30 years. The forest harvest level dropped to about 65% after the 2008 housing crash and then increased to 71% by 2017 (Government of Canada, 2020).

2.3. Drivers of change in the forest sector and their consequences for forest genetic resources

Climate change is a major driver of change in forests and the forest sector, both directly and indirectly via fire-, insect-, or pathogen -related impacts on forest ecosystem function, and tree health or composition, with consequent changes in park and urban forest management and impacts on human livelihoods. For example, although the total area of Canada’s forested land burned by fire has not increased significantly over the past 20 years, fires in recent years have occurred in locations where they are historically uncommon. In British Columbia, large areas of pine that were killed by beetles as a result of climate change burned in 2018 (Natural Resources Canada, 2020). As a second example, climate change also alters tree genetic resources through habitat loss (e.g., *Pinus albicaulis* and *Pinus monticola*, McLane and Aitken 2012, Liu *et al.*, 2016). The effects of climate change have highlighted the vital need to effectively manage tree genetic diversity, since available genetic variation is as a key natural resource for adaptive response or resilience of trees to the stresses resulting from climate change (Aitken and Bemmels, 2016).

Forest invasive alien species (FIAS; insect or pathogen) constitute a second significant driver of change in the forest sector, in both natural and urban forests (Toronto and Region Conservation Authority, 2020; Table 2.3). Populations of tree species have been lost to invasive species, taking with them undocumented genetic diversity. Similar to the effects of climate change noted above, impacts by invasive species highlight the need for inventorying and conservation of tree genetic diversity as a natural non-renewable resource for adaptive variation or resistance to FIAS impacts (Forest Gene Conservation Association, 2018).

Table 2.3. Extent of forest defoliation by insect or pathogens, and losses due to fire, from 2012 to 2018.

Disturbance[1]	2012	2013	2014	2015	2016	2017	2018
Insects							
All insect species	8,796,129	20,129,334	20,391,494	15,730,947	15,489,117	15,628,659	
Balsam fir sawfly					591		
Forest tent caterpillar				4,841,071	4,013,393		
Gypsy moth				757			
Jack pine budworm				24,634	206,849		
Mountain pine beetle	3,016,228	2,973,935	2,208,687	1,447,954	376,669	332,259	
Spruce beetle				242,877	291,972		
Spruce budworm	1,792,062	2,777,998	3,583,700	5,235,854	4,970,951		
Western spruce budworm				9,135	3,426		
Other insects				3,928,665	5,625,266		
Fire							
Total burned	2,003,270	4,210,137	4,563,327	3,861,647	1,416,053	3,371,833	2,272,274
Number of fires	7,956	6,264	5,158	7,140	5,203	5,611	7,067

1. All measures in hectares except for final row (counts).

Successful regeneration is required by provincial crown land authorities and this can be accomplished through natural regeneration, planting, or seeding. The area seeded increased from 2012 to 2017 and the total area artificially regenerated (seeded or planted) has been relatively stable since 2017 (Table 2.4). The percentage of the area harvested that was artificially regenerated varied from 50% (2012) to 58% (2013 and 2014) during this period. Most seed used in artificial regeneration is sourced from seed orchards and genetic variation represented by the seeds may be narrow, particularly in terms of rare alleles. Even so, artificial regeneration allows managers to match seed source to environmental conditions, a practice considered increasingly important in attempts to regenerate harvested forests with genotypes that are potentially well-adapted to local climate conditions or insect or pathogen pressures.

Table 2.4. Forest Harvest and reforestation.

Impact[1]	2012	2013	2014	2015	2016	2017
Harvest						
Area harvested	711,411	745,800	714,489	778,331	766,659	756,295
Volume harvested	153,184,768	155,530,548	155,135,729	160,163,661	156,743,605	156,717,595
Regeneration						
Area planted	348,730	420,494	403,006	415,264	410,221	409,559
Area seeded	10,540	11,197	11,906	13,050	15,790	17,866
Third-party certification						
Area certified	147,928,855	152,937,728	160,856,360	166,163,538	167,797,442	169,865,528

1. Area represents hectares, volume represents cubic metres.

2.4. Challenges and opportunities for the conservation, development, and use of forest genetic resources

Challenges

Provincial representatives noted climate change as a pressing challenge. British Columbia is implementing Climate Based Seed Transfer (CBST) as a strategy to hasten adaptation to local effects of climate change. The aim of CBST is to ensure that forests will be healthy, resilient and productive by matching seed source to planting sites in light of site-specific projected local climate conditions. While proactive, this management effort produces challenges for predicting future climate regimes, genotypes best suited to those conditions, and for preparing tree breeding populations, seed orchard composition, and seed procurement and deployment to act on those predictions. While the province manages around the mean responses of predictions (e.g., breeding value calculations, climate change response surfaces), foresters must manage variability in realized climatic conditions at the scale of within-site variation. Provincial policy does not address this fine spatial scale adequately in its timber harvesting plans, and in addressing all challenges that industry might have in obtaining suitable tree accessions. Notably, building more resilient forests requires detailed research that must be shared by government and industry. Related to this issue, the increasing impacts of fire, insects or pathogens, and disease under relatively rapid climate change diminish the benefits of FGR management and, in turn, industrial support for this practice. Consequently, government agencies will need to invest substantially in FGR research and management.

Breeding for multiple traits is a challenge noted by two provincial jurisdictions. The complexity of this issue has increased with the need to combine former priority adaptive traits with those addressing the emerging bioeconomy. An inherent constraint of meeting this challenge is that multi-trait index selection is only possible in cases where traits are strongly correlated, which poses a challenge for diversifying forest product needs.

All jurisdictions noted that accessing consistent, adequate funding for long-term breeding programs presents an ongoing challenge. As selective tree breeding programs mature, managing advancing generations in breeding populations becomes more complex, yet resources to do so continue to lag or to vary across years.

Opportunities

Climate change and the threats posed by insects and pathogens (including FIAS) provide opportunities for FGR in Canada. Overall, they drive research and conservation of FGR aimed at fostering resilience and adaptation of planting material to new biotic and abiotic threats. The increased demand for climate-adapted material necessitates genetic evaluation to choose suitable material and this supports seed transfer revisions. Similar efforts have been initiated to develop insect and pathogen resistance in species including elm (*Ulmus americana*), white pine (*Pinus strobus*), butternut (*Juglans cinerea*) and beech (*Fagus grandifolia*). More broadly, there is a vital need to inventory species-specific genetic diversity across natural forests, as a means to identify existing levels of this non-renewable resource and to prioritize stands for FGR conservation.

Increased human pressures on the productive forest land base have also prompted research on FGR, in order to meet demands for higher production over reduced areas. For example, Ontario plans to double the volume harvested while staying within its AAC, by planting more selectively bred seedlings to increase productivity and ensure wood supply sustainability.

Several related trends affect progress on inventorying and developing Canada's FGR. First, consolidation of forest industry in recent years has improved prospects for forest management, given that large companies are more likely to have selective tree breeding programs. Canada's 2 billion tree initiative, announced by the Liberal government in 2019, offers additional opportunities for supporting selective breeding, particularly considering the need for planting material that is adapted to future climates. Finally, carbon credits may provide an opportunity for incremental benefits of selective breeding if selected trees grow more rapidly.

Literature Cited

Aitken, S.N. and Bemmels, J.B., 2016. Time to get moving: assisted gene flow of forest trees. Evolutionary Applications, 9(1), pp.271-290.

British Columbia Ministry of Environment. 2016. Indicators of Climate Change for British Columbia 2016 Update https://www2.gov.bc.ca/assets/gov/environment/research-monitoring-and-reporting/reporting/envreportbc/archived-reports/climate-change/climatechangeindicators-13sept2016_final.pdf Accessed September 2020

Forest Gene Conservation Association. 2018. https://fgca.net/programs/ Accessed September 2020.

Government of Canada. 2020. https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/sustainability-timber-harvest.html Accessed September 2020

McLane, S.C. and Aitken, S.N., 2012. Whitebark pine (Pinus albicaulis) assisted migration potential: testing establishment north of the species range. Ecological Applications, 22(1), pp.142-153.

Natural Resources Canada. 2020. The State of Canada's Forests Annual Report 2019. Ottawa, Canada. 77 p. http://cfs.nrcan.gc.ca/stateoftheforests

Liu, J.J., Sniezko, R., Murray, M., Wang, N., Chen, H., Zamany, A., Sturrock, R.N., Savin, D. and Kegley, A., 2016. Genetic diversity and population structure of whitebark pine (Pinus albicaulis Engelm.) in western North America. PloS One, 11(12).

Toronto and Region Conservation Authority. 2020. https://trca.ca/conservation/habitat-protection-regeneration/emerald-ash-borer/ Accessed September 2020.

Chapter 3. State of diversity in other wooded lands

This chapter presents an overview of the state of other wooded lands and other land with tree cover in Canada and a review of the trends that are shaping them. It identifies the main drivers of change and analyses their consequences, specifically for forest genetic resources (FGR).

Other wooded land is defined as an area: 1) with a total of 5-10% canopy cover with a mature tree height of 5 metres or more, or; 2) with woody species (shrubs/trees) that cover more than 10% of the land, excluding urban and agricultural areas (Natural Resources Canada, 2018). These include treed wetlands (swamps and bogs) and other land with slow-growing and scattered trees.

FAO defines other wooded land in essentially the same way, and both Natural Resources Canada and FAO (2018) define "other land with tree cover" as land that is not classified as forest or other wooded land but spans more than 0.5 ha with a canopy cover of more than 10 percent, of trees able to reach a height of 5 meters at maturity. This includes agroforestry and trees in urban settings. Table 3.1 provides definitions of each type of treed lands outside of forests.

3.1. The state of other wooded lands and other lands with tree cover

Other wooded lands and other lands with tree cover consist of about 12.5% of the total tree-covered lands in Canada, covering about 5% of the country's terrestrial land area. Other wooded land consists mostly of wooded wetland, and covers 40,865,660 ha, primarily in the Boreal Forest Region. Other land with tree cover including urban forest and treed agricultural land, accounts for 8,498,940 ha (Natural Resources Canada, 2020). These lands have a disproportionately strong importance in providing ecosystem services. Data are needed to assess the sustainable natural resource management and species conservation on these lands, and also to determine their greenhouse gas emissions (Lowe *et al.*, 2000; Smith *et al.*, 2018).

Wetlands are defined as land that is saturated with water all or most of the time, as indicated by poorly drained soils and vegetation, and by biological activity adapted to wet environments (Government of Canada, 2010). The National Wetlands Working Group (1997) classified wetlands as fens, bogs, swamps, marshes and shallow water. Fens, bogs and swamps may host trees and much of the treed wetland in Canada is swamp. The National Wetlands Working Group (1997) noted that:

> "*The term swamp has been used in Canada to refer to forested or wooded wetlands and peatlands. The treed swamps have also been called swamp forest or forested wetland. A swamp can be defined as a treed or tall shrub (also called thicket) dominated wetland that is influenced by minerotrophic groundwater, either on mineral or organic soils. The essential features of the swamp class are the dominance of tall woody vegetation, generally over 30% cover, and the wood-rich peat laid down by this vegetation*."

Wetlands are among the earth's most productive ecosystems. In Canada, wooded wetlands are the most significant component of treed lands not classified as forest, in terms of spatial area, biodiversity, and provision of a variety of ecosystem services. However, precise information regarding the location and extent of wooded wetlands is lacking.

The total area in Canada that is categorized by the federal government as wetlands is approximately 129 million ha comprising 13% of Canada's terrestrial area and almost 25% of the world's remaining wetland. However, Landsat-8 surface reflectance images indicate that wetlands in fact cover more than 35% of Canada's area and that 40% of that may be wooded (Amani *et al.*, 2018). If 40% of the wetlands defined more narrowly by Environment and Climate Change Canada (2016) are wooded, it represents 51.6 million ha. However, some of this area is classified federally as forest because canopy cover exceeds 10%. About 80% of Canada's wetlands are located in the Boreal Forest. Within the Boreal Forest, most of Canada's wetlands occur in three ecozones: Boreal Shield (25% of Canadian wetland area), Hudson Plains (21%) and Boreal Plains (18%). Wetlands form almost 80% of the Hudson Plains. By contrast, mountainous ecozones such as the Arctic Cordillera (less than 0.5%) and Montane Cordillera (less than 2%) have very small proportions of Canada's wetlands (Environment and Climate Change Canada, 2016).

Table 3.1 Types of other wooded land and other land with tree cover.

Land type	Definition	Region	Area (ha)
Other Wooded Land			40,865,660
Wooded wetlands	Areas where water table is at or below the surface with standing or flowing water and vegetation is characterised by trees or shrubs greater than 1 m in height (Amani, *et al*. 2018).	More than 80% in Boreal Forest	
Scattered trees	Areas where harsh environment or low moisture level prevents development of continuous forest canopy.	Northern treeline, western montane areas, Carolinian savanna	
Other Land with Tree Cover			8,498,940
Shelterbelts	Trees of various sizes planted linearly alongside farmsteads or agriculture fields to protect or shelter infrastructure, equipment, livestock, crops and soil from wind or other climatic conditions (Ha 2019, Kulshreshtha, *et al*. 2019).	Manitoba, Saskatchewan, Alberta, and British Columbia (Peace River region)	

Land type	Definition	Region	Area (ha)
Riparian areas	Treed buffer zone between agricultural land and bodies of water intended to stabilize erosion, physically separate agricultural activities from sensitive aquatic areas, and protect water quality.	All	
Urban forest	Trees, forests, greenspace and related abiotic, biotic and cultural components in areas extending from the urban core to the urban-rural fringe (Tree Canada 2019).	All	

As much as 60% of the wetland in the boreal forest is classified by Wulder *et al.* (2018) as being tree covered ("treed"). This implies that at least 60 million ha or more wooded wetland occurs in the boreal forest. However, Wulder's distinct definition of wooded land (minimum 1 m height and 30% cover) renders it difficult to determine precisely the proportion of other wooded land that is comprised of wooded wetland. Canada does not yet have a national wetland monitoring system or a detailed wetland classification. Promising work in that direction has been published by Amani *et al*. (2019) who used Landsat-8 imagery and image processing technology available in the Google Earth Engine to produce a preliminary country-wide map classifying wetlands into bog, fen, marsh, swamp and shallow water categories.

Target 3 of the 2020 Biodiversity Goals and Targets for Canada is: "Canada's wetlands are conserved or enhanced to sustain their ecosystem services through retention, restoration and management activities." The focus is on waterfowl and several achievements are highlighted, including "in 2016, in the western boreal forest part of the Prairie Habitat Joint Venture, the Government of Saskatchewan approved a forest company's 20-year forest management plan that includes the protection of habitat for Woodland Caribou and other wildlife totalling approximately 207,000 ha, of which approximately 80% are wetlands."

At least 36 tree species in Canada are found in wooded wetlands (Farrar, 1995; Table 3.2). Although only seven of these are conifers, most wooded wetland in the boreal forest is dominated by *Picea mariana* and *Larix laricina*. One-quarter of the listed species are rare deciduous species that occur only in the Carolinian region of southern Ontario. Other species, such as *Pinus strobus* and *P. monticola*, are usually found in upland habitats but are sometimes located in bogs.

Other wooded land besides wooded wetland includes areas at or near alpine and boreal treelines, scattered trees in grasslands and barrens. Table 3.2 lists 24 species in this category, including subalpine species such as *Pinus albicaulis* and *P. flexilis*, both of which are threatened by disease and climate change-induced habitat loss, and species found at the northern treeline (e.g., *Picea glauca*). Canada has a small area of savanna, located mainly in the Carolinian forest in southern Ontario, which consists of grassland with scattered trees. Savanna is rare in Canada and this habitat hosts plant species that are also rare and in some cases threatened (e.g., *Ptelea trifoliata*).

A small but environmentally significant component of other lands with tree cover is the agroforestry use of trees in agricultural lands, such as in shelterbelts or for riparian protection. Shelterbelts are used primarily in the prairies to protect homesteads and reduce erosion in fields. Piwowar *et al.* (2016) quantified shelterbelts in Saskatchewan and estimated that shelterbelts consisting of trees (as opposed to shrubs) cover about 41,838 km (41.8 square km; Mayrinck *et al*., 2019). Although there is a long history of shelterbelt use in Canada (Mayrinck, 2019), the rate of removal outpaces their establishment now (Ha *et al.,* 2019). The Agriculture and Agri-Food Canada Agroforestry Development Centre at Indianhead, Saskatchewan (previously the Prairie Farm Rehabilitation Administration shelterbelt program) ran an active tree and shrub breeding program for shelterbelt development until its termination in 2013. During its 127-year operation, the program produced selectively bred seed for more than 20 species of trees and shrubs (Schroeder, 2015). Table 3.2 lists nine native species that have been commonly planted in shelterbelts. Several non-native tree and shrub species have also been used extensively in shelterbelt plantings.

Urban forest accounts for a significant and growing area of other lands with tree cover; estimated in 2011 to be 31,041 square km for the country's 34 largest metropolitan areas (Statistics Canada, 2018). Table 3.2 lists 30 native tree species found in Canada's urban forests. This is a partial list of species that are planted on city streets and in city parks.

Tree Canada, a non-profit charity aiming to improve lives of Canadians by planting and maintaining trees, is the secretariat for the current iteration of the Canadian Urban Forest Strategy. The Strategy's Vision is: "to have sustainable, biodiverse and healthy urban forests that protect and enhance the well-being and prosperity of Canadian communities." Urban trees grow in a difficult environment, as a result of limited growing space combined with a variety of contaminants and potential physical damage which can predispose them to insect and disease attack. When this is combined with low genetic diversity due to over-representation of relatively few species, many of which are grown from cultivar grafts (Tree Canada, 2019), trees in urban environments are particularly targeted by invasive pests (e.g., Dutch elm disease and Emerald ash borer), the result of cities frequently serving as ports of entry for exotic invasive pests.

3.2. Trends affecting other wooded lands and other lands with tree cover, and their management

Wulder *et al*. (2018) assessed changes in extent of wooded and non-wooded wetlands and found that, overall, the status of wetlands was generally stable over the period from 1984 to

2016 with regional variability. They reported that across the forested ecozones, the extent of treed wetlands increased but non-treed wetlands lost area. In the southern boreal forest, the extent of wetlands declined as a result of increased drought severity and changing patterns of surface water. In the northern boreal forest, the extent of wetlands increased because of the effect of thawing permafrost. Although data are lacking, it is expected that the area of wetlands supporting trees will increase in these areas as the climate continues to change. Wulder *et al.* (2018) reported that ecozone showing the greatest change in extent of wetlands was the Maritime Atlantic Ecozone, where wetlands declined by 1.3% per year over the three decades ending in 2016. The reason for the decline appears to be a combination of increased drought frequency and severity along with urban development.

Outside of wooded wetlands, tree species found on other wooded lands are affected by a number of factors. Climate change leads to changes in the elevation and latitude of treelines, while agricultural or urban development of the savanna typically degrades or eliminates wooded lands.

Urban forests are also influenced by climate change, given that the impact of warmer and drier summers is exacerbated by the urban environment. Bardekjia, *et al.* (2016) noted that urban forest managers representing 68 Canadian municipalities reported that while urban woodland and the number of trees on city streets is increasing, the amount of natural cover is decreasing. There is a growing trend for trees and woodlands to be viewed as important by residents. The top pressures for urban forests are urban development, and insufficient funding and planning. Almas and Conway (2017) reported a trend for urban forest management plans to include planting a higher proportion of native species than was previously the case.

3.3. Drivers of change in other wooded lands in your country, and their consequences for forest genetic resources

Climate change is the most significant driver of change in other wooded lands in Canada because of its impact on wetlands. In southern areas, climate change has led to a reduced extent of wetlands, including wooded wetlands. Conversely, the area of wetland has expanded in the northern Boreal Forest (Wulder *et al.*, 2018). Fire occurrence in wooded wetlands, particularly peatlands, has increased over past decades and is expected to continue to increase as a result of climate change.

Exotic invasive insects and diseases threaten tree populations in treed areas that are not classified as forest. In particular, Emerald ash borer drives decline and loss of populations of black ash (*Fraxinus nigra*) in deciduous and mixed deciduous/coniferous swamps, and in urban forest.

The greatest area of other wooded lands is populated by a low number of broadly distributed wind-pollinated tree species that contain high genetic diversity. Yet, the wooded wetlands and sparsely treed savanna areas in southern Ontario that fall within the other wooded lands category contain a proportionally rich suite of tree species. Many of these are rare and some are also insect-pollinated (e.g., *Asimina triloba*), rendering them susceptible to loss of genetic diversity under decreased population size. Urban development is the most significant driver of change for these species.

Table 3.2 Main native tree species present in “other wooded land” and “other land with tree cover” categories.

Species	**Wooded wetlands**	**Scattered Trees**	**Shelter-belts**[1]	**Agricultural Riparian areas**	**Urban Forest**
Acer negundo	X		X	X	X
Acer nigrum					X
Acer rubrum	X			X	X
Acer saccharinum	X				X
Acer saccharum					X
Abies balsamea	X			X	
Abies lasiocarpa		X			
Alnus incana ssp. *rugosa*	X			X	
Aesculus glabra					X
Asimina triloba	X				
Betula neoalaskana (syn. *B. pendula*)	X				
Betula papyrifera					X
Carpinus caroliniana	X				
Carya glabra		X			
Celtis occidentalis					X
Cephalanthus occidentalis	X				
Crataegus spp.				X	
Euonymus atropurpureus	X				
Fraxinus americana					X
Fraxinus nigra	X				
Fraxinus pennsylvanica	X		X		X
Gymnocladus dioicus					X
Juglans nigra					X
Juniperus scopulorum		X			
Juniperus virginiana		X			
Larix laricina	X				
Larix lyallii		X			
Liriodendron tulipifera	X				X
Magnolia acuminata					X
Nyssa sylvatica	X				X
Ostrya virginiana					X
Picea engelmannii		X			
Picea glauca		X	X	X	X
Picea mariana	X				

Species	Wooded wetlands	Scattered Trees	Shelter-belts[1]	Agricultural Riparian areas	Urban Forest
Picea sitchensis					X
Pinus albicaulis		X			
Pinus banksiana	X	X			
Pinus contorta var *contorta*	X	X			
Pinus flexilis		X			
Pinus monticola	X				
Pinus resinosa		X			
Pinus rigida		X			
Pinus strobus	X	X			X
Platanus occidentalis	X				
Populus balsamifera	X			X	
Populus x *deltoides*			X		
Populus spp.			X	X	
Populus tremuloides			X	X	
Prunus pensylvanica		X	X	X	X
Prunus serotina					X
Prunus virginiana				X	
Pseudotsuga menziesii					
Ptelea trifoliata		X			
Quercus alba		X			X
Quercus bicolor	X	X			X
Quercus macrocarpa	X	X	X		X
Quercus muehlenbergii		X			X
Quercus palustris	X	X			
Quercus rubra		X			X
Quercus schumardii	X				
Quercus velutina		X			
Salix amygdaloides	X				
Salix bebbiana				X	
Salix discolor	X			X	
Salix lucida	X				
Salix nigra	X				
Salix pyrifolia	X				
Salix rigida				X	
Tilia americana					X
Thuja occidentalis	X	X			X
Thuja plicata	X				X
Toxicodendron vernix	X				
Tsuga heterophylla					
Ulmus americana	X		X	X	X

1. Sources: Amichev *et al.,* 2015; Kort & Turnock, 1999; Kulshreshtha *et al.*, 2019; Wiseman *et al.*, 2009.

3.4. Challenges and opportunities these trends and drivers create for the conservation, use and development of forest genetic resources

The main challenge for the conservation, use and development of FGR in wooded wetlands is the lack of inventory data and monitoring protocols. By far the greatest area of other wooded land is in a mid-latitudinal cross-Canada band where human population density is low and access is often poor. Industrial forestry does not occur on these lands so they are frequently absent from forest inventories. There is little immediate economic incentive to expend the financial resources that would be necessary for detailed assessment and ongoing monitoring.

Several tree species that occur as scattered trees in other wooded lands, such as *Pinus albicaulis* and *P. flexilis*, are listed in Canada's Species at Risk registry and have recovery plans that include consideration of genetic resources (Alberta Ministry of Agriculture and Forestry (2019).

Specific area data on shelterbelts is lacking, but research into new imaging and mapping techniques to locate shelterbelts is ongoing. The resulting data are being used to assess shelterbelt potential for carbon sequestration as woody biomass and soil organic carbon, as well as for identifying potential tree removals (Amichev *et al.*, 2015; Ha *et al.* 2019; Kort & Turnock, 1999; Wiseman *et al.*, 2009; Kulshreshtha & Kort, 2009; Baah-Acheamfour *et al.*, 2014). Following the 2013 termination of the breeding program for prairie shelterbelts, shelterbelt planting has declined in Canada (Schroeder, 2015).

The area, species composition, and significance of agricultural riparian zones is not well documented. However, all jurisdictions in Canada have regulations for riparian buffer zones to protect aquatic habitats from forestry, agriculture, and commercial, industrial, and residential development.

A major challenge to the conservation, use, and development of genetic resources of urban forest tree species is the impact of invasive insects and disease. This impact has prompted funding for genetic research to develop resistant tree species varieties. The first urban forest crisis related to exotic pests was the spread of Dutch elm disease through Canadian municipalities, which resulted in the death of many street and park trees. Elms trees (*Ulmus* spp.) were often replaced by ash (*Fraxinus* spp.), and these are now the focus of attack by emerald ash borer. Emerald ash borer invaded Ontario first but is spreading east and west, now found in Winnipeg, Manitoba from 2017, and reaching Edmundston, New Brunswick in 2018 (Tree Canada, 2019).

Literature Cited

Alberta Ministry of Agriculture and Forestry. 2019. Limber and Whitebark Pine Recovery in Alberta. ISBN 978-1-4601-4535-7

Almas, A.D. and Conway, T.M., 2017. Residential knowledge of native tree species: A case study of residents in four southern Ontario municipalities. Environmental management, 59(1), pp.21-33.

Amani, M., Mahdavi, S., Afshar, M., Brisco, B., Huang, W., Mohammad Javad Mirzadeh, S., White, L., Banks, S., Montgomery, J. and Hopkinson, C., 2019. Canadian wetland inventory using Google Earth engine: the first map and preliminary results. Remote Sensing, 11(7), p.842.

Amani, M., Salehi, B., Mahdavi, S. and Brisco, B., 2018. Spectral analysis of wetlands using multi-source optical satellite imagery. ISPRS Journal of Photogrammetry and Remote Sensing, 144, pp.119-136.

Amichev, B.Y., Bentham, M.J., Cerkowniak, D., Kort, J., Kulshreshtha, S., Laroque, C.P., Piwowar, J.M., Van Rees, K.C.J. 2015. Mapping and quantification of planted tree and shrub shelterbelts in Saskatchewan, Canada. Agroforestry Systems 89: 49–65.

Baah-Acheamfour, M., Carlyle, C.N., Bork, E.W., and Chang, S.X. 2014. Trees increase soil carbon and its stability in three agroforestry systems in central Alberta, Canada. Forest Ecology and Management 328: 131-139.

Bardekjian, A., Kenney, A., & Rosen, M. 2016. Trends in Canada's Urban Forests. Tree Canada and the Canadian Urban Forest Network.

Environment and Climate Change Canada. 2016. Canadian Environmental Sustainability Indicators: Extent of Canada's Wetlands. www.ec.gc.ca/indicateurs-indicators/default.asp?lang=en&n=69E2D25B-1.

Farrar, J.L., 1995. Trees in Canada. Fitzhenry & Whiteside Ltd., Markham, Ont., and Canadian Forest Service. Natural Resources Canada, Ottawa, Ont, 502 p.

Food and Agriculture Organization of the United nations. 2018. Global Forest Resources Assessment 2020. Terms and Definitions. Forest Resources Assessment Working Paper 188, Rome, Italy, 32 pp.

Ha, T.V., Amichev, B.Y., Belcher, K.W., Bentham, M.J., Kulshreshtha, S.N., Laroque, C.P., and Van Rees, K.C.J. 2019. Shelterbelt agroforestry systems inventory and removal analyzed by object-based classification of satellite data in Saskatchewan, Canada. Canadian Journal of Remote Sensing DOI:10.1080/07038992.2018.1540297

Kort, J., and Turnock, R. 1999. Carbon reservoir and biomass in Canadian prairie shelterbelts. Agroforestry Systems 44: 175–186.

Kulshreshtha, S.V., Ahmad, R., Belcher, K., and Rudd, L. 2019. Economic-environmental impacts of shelterbelts in Saskatchewan, Canada. Pages 277-286 in J. Casares, G. Passerini, and G. Perillo, editors. WIT Ecology and the Environment Environmental Impact 2018. WIT Press, Southampton, UK.

Kulshreshtha, S., and Kort, J. 2009. External economic benefits and social goods from prairie shelterbelts. Agroforestry Systems 75: 39–47.

Löwe, H., Seufert, G., and Raes, F. 2000. Comparison of methods used within Member States for estimating CO2 emissions and sinks according to UNFCCC and EU Monitoring Mechanism: forest and other wooded land. Biotechnol. Agron. Soc. Environ. 4: 315–319.

Mayrinck, R.C., Laroque, C.P., Amichev, B.Y. and Van Rees, K., 2019. Above-and below-ground carbon sequestration in Shelterbelt trees in Canada: a review. Forests, 10(10), p.922.

Natural Resources Canada. 2018. Statistical Data. NRCan, Ottawa, ON, Canada. [online] URL: https://cfs.nrcan.gc.ca/statsprofile/inventory/canada Accessed January 2019.

Natural Resources Canada. 2020. The State of Canada's Forests; Annual Report 2019. Ottawa, ON. 77 p.

Piwowar, J.M., Amichev, B.Y. and Van Rees, K.C., 2016. The Saskatchewan shelterbelt inventory. Canadian Journal of Soil Science, 97(3), pp.433-438.

Schroeder, W. 2015. Reflections on prairie tree breeding: 1888 to 2015. Conference presentation abstract. Canadian Forest Genetics Bi-annual Conference, August 17-20, 2015. Fredericton, NB.

Smith, W.B., Cuenca Lara, R.A., Caballero, C.E.D., Valdivia, C.I.G., Kapron, J.S., Reyes, J.C.L., Tovar, C.L.M., Miles, P.D., Oswalt, S.N., Salgado, M.R., Song, X.A., Stinson, G., and Gaytán, S.A.V. 2018. The North American Forest Database: going beyond national-level forest resource assessment statistics. Environmental Monitoring and Assessment 190: 350.

Statistics Canada. 2018. Human Activity and the Environment 2017: Forests in Canada. Catalogue no. 16-201-X, ISSN 1923-6751

Tree Canada. 2019. Canadian Urban Forest Strategy 2019 – 2024. Available at https://treecanada.ca/wp-content/uploads/2019/04/TC-CUFS-2019-2024-Eng.pdf

Warner, B.G. and Rubec, C.D.A. (Eds.) 1997. The Canadian Wetland Classification System, Second Edition. Wetlands Research Centre, University of Waterloo, Waterloo, Ontario, 76 pp.

Wiseman, G., Kort, J., Walker, D. 2009. Quantification of shelterbelt characteristics using high-resolution imagery. Agriculture, Ecosystems and Environment 131: 111–117.

Wulder, M.A., Li, Z., Campbell, E.M., White, J.C., Hobart, G., Hermosilla, T. and Coops, N.C., 2018. A national assessment of wetland status and trends for Canada's forested ecosystems using 33 years of earth observation satellite data. Remote Sensing, 10(10), p.1623.

Chapter 4. State of diversity between trees and other woody plant species

Canada encompasses great climatic and landform diversity, which leads to very different forest conditions in different areas of the country. The diversity of tree species is greatest in southern Ontario and in contrast, there is very low tree species diversity near the northern treeline. Table 4.1 lists tree species that characterize Canada's 15 terrestrial Ecozones. Ecozones are defined on the basis of climate, landform and regional vegetation patterns. The Mixed wood Plains ecozone covering the smallest area contains over half of Canada's endangered and threatened species, including the common hoptree (*Ptelea trifoliata*), cucumber tree (*magnolia acuminata*), dwarf hackberry (*Celtis tenuifolia*), American chestnut (*Castanea dentata*), cherry birch (*Betula lenta*), Kentucky coffeetree (*Gymnocladus dioicus*), and red mulberry (*Morus rubra*). About 17% of Canada's landmass is located in the far north and does not support trees although woody species in shrub form, such as birch (*Betula* spp.) and willow (*Salix* spp.), occur there.

Table 4.1 Canadian terrestrial ecozones and characteristic tree species (From Canada's 2012 FGR Report).

Ecozones	**Area (km^2)**	**Percentage of land are**	**Characteristic native tree species by ecozone**
Arctic Cordillera	230 873	2.5	N/A
Northern Arctic	1 361 433	14.8	N/A
Southern Arctic	773 010	8.4	stunted *Picea mariana*
Taiga Cordillera	264 480	3.0	stunted *Abies lasiocarpa, Betula papyrifera, Picea glauca, Picea mariana, Pinus contorta* var. *latifolia, Populus balsamifera, Populus tremuloides*
Taiga Plains	580 139	6.4	*Alnus viridis* ssp. *Crispa, Betula papyrifera, Larix laricina, Picea glauca, Picea mariana, Pinus banksiana, Populus balsamifera, Populus tremuloides, Salix* spp.
Taiga Shield	1 253 887	13.6	*Alnus viridis* ssp. *crispa, Betula papyrifera, Larix laricina, Picea glauca, Picea mariana, Pinus banksiana, Populus tremuloides*, *Salix* spp.
Hudson Plains	353 364	3.8	*Betula papyrifera, Larix laricina, Picea mariana, Picea glauca, Populus balsamifera*
Boreal Cordillera	459 680	5.0	*Abies lasiocarpa, Betula papyrifera, Picea glauca, Picea mariana, Pinus contorta* var. *latifolia, Populus balsamifera, Populus tremuloides*
Boreal Plains	679 969	7.4	*Abies balsamea, Acer negundo, Larix laricina, Picea glauca, Picea mariana, Pinus banksiana, Populus tremuloides, Populus deltoides* ssp. *deltoides*

Ecozones	Area (km²)	Percentage of land are	Characteristic native tree species by ecozone
Boreal Shield	1 782 252	19.3	*Abies balsamifera, Acer negundo, Acer saccharum, Betula alleghaniensis, Betula papyrifera, Fraxinus nigra, Larix laricina, Picea glauca, Picea mariana, Pinus banksiana, Pinus resinosa, Pinus strobus, Populus tremuloides, Thuja occidentalis, Viburnum trilobum*
Prairies	520 000	5.0	*Acer negundo, Amelanchier alnifolia, Populus balsamifera, Populus tremuloides*
Montane Cordillera	459 680	5.0	*Abies lasiocarpa, Picea engelmannii, Picea glauca, Pinus contorta* var. *latifolia, Pinus monticola, Pinus ponderosa, Populus tremuloides, Pseudotsuga menziesii* var. *glauca, Thuja plicata, Tsuga heterophylla*
Pacific Maritime	205 175	2.2	*Abies amabilis, Alnus rubra, Callitropsis nootkatensis, Cornus nuttalli, Picea sitchensis, Pseudotsuga menziesii* var. *glauca, Thuja plicata, Tsuga heterophylla, Tsuga mertensiana*
Atlantic Maritime	183 978	2.0	*Abies balsamifera, Acer rubra, Acer saccharum, Alnus incana, Betula alleghaniensis, Betula papyrifera, Fagus grandifolia, Fraxinus nigra, Picea mariana, Picea rubens, Picea glauca, Pinus banksiana, Pinus resinosa, Pinus strobus, Prunus pensylvanica, Quercus rubra, Tsuga canadensis*
Mixedwood Plains	175 963	2.0	*Acer saccharum, Betula alleghaniensis, Juglans cinerea, Pinus resinosa, Pinus strobus, Quercus bicolor, Quercus rubra, Tilia Americana, Thuja occidentalis, Tsuga canadensis, Ulmus Americana, Fraxinus quadrangulate, Gymnocladus dioicus, Juglans nigra, Liriodendron tulipifera, Magnolia acuminate, Morus rubra, Platanus occidentalis*

Canada's ecozones are subdivided into 194 ecoregions that vary greatly in number and composition of tree species. Figure 4.1 illustrates the number of tree species by overarching ecoregion groupings, with 1-8 species in the most northern treed ecoregions and as many as 95 tree species in the temperate Lake Erie Lowland ecoregion (the southernmost in Canada). The southern limits of the Lake Erie Lowland ecoregion are at the same latitude as northern California. This region is highly influenced by the moderating effect of the lower Great Lakes.

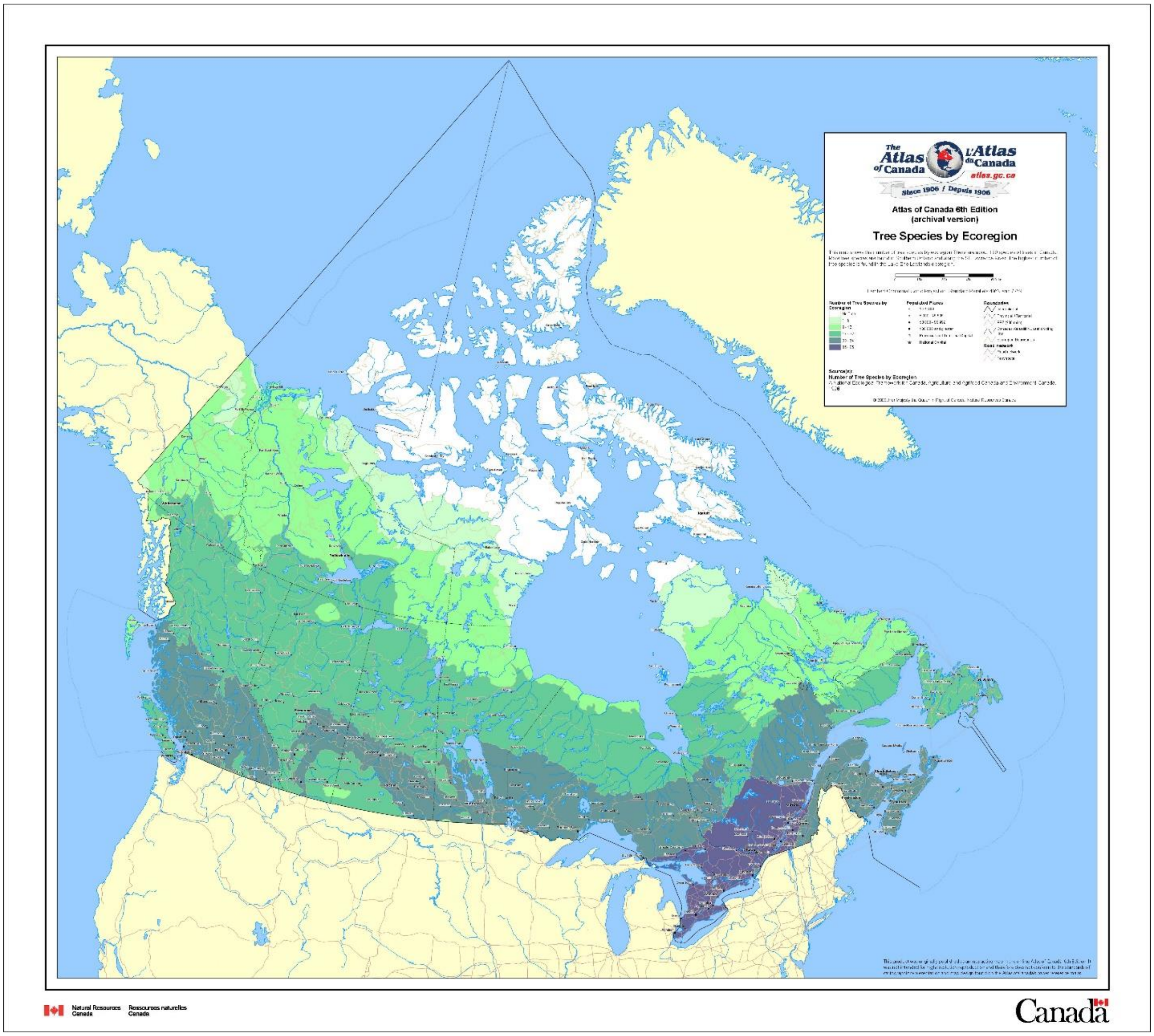


Figure 4.1. Number of tree species by ecoregion from the Atlas of Canada, (Natural Resources Canada, 2019).

4.1. Tree and other woody plant species considered as genetic resources

More than 400 native tree and shrub species are found in Canada, of which 126 are trees (defined as reaching a height of at least 10m, Farrar 1995) (Table 4.2). All native tree and shrub species can be considered as genetic resources because all have current or potential importance for ecosystem integrity and conservation values, wood or non-wood forest products, urban planting, ecological restoration, or for contributing to Canada's emerging bioeconomy. About 45 tree species are managed for commercial forestry. Urban forest managers are increasingly looking for native tree species (Almas and Conway, 2016) but some of the most common choices in the past, such as *Fraxinus* species, are now used much less because of insect and disease challenges. Many species, particularly shrubs that would not have been considered important beyond their ecological value, are now under consideration for habitat restoration and mine-site reclamation purposes (Fraser *et al.* 2014).

Some woody species (mainly Carolinian species in southern Ontario) are at their northern edge range in Canada and occur only in small populations that are threatened by land use pressures (McCune and Morrison, 2020). These are considered as valuable genetic resources to be managed and conserved, in part because of their potential for range expansion and subsequent greater significance in future ecosystems.

4.2. Proportion of species that are native (including naturalized species) and introduced

The vast majority of trees growing in Canada are native species, and trees planted for forestry and restoration are almost always native species. Increasingly, trees used for urban planting are also native, especially for municipalities that follow a management plan (Almas and Conway, 2016). Beginning in the 1930s, forest scientists tested a number of exotic tree species for potential use by Canada's forest industry (Holst and Heimburger, 1969), but native species have consistently out-performed exotic species. Except for Norway spruce (*Picea abies*) (Fowler and Coles 1980) which still has limited use in eastern Canada, commercial forest species are native. It is noteworthy that the concept of exotic or non-native species is different from that of smaller countries because of Canada's size. With a few exceptions, tree species found on the west coast are distinct from those found in the east (Farrar 1995), so a Canadian tree species planted a few thousand km from its native range is non-native to the area where it is planted.

Urban planting has historically made use of many exotic tree species but the proportion of exotic to native tree species used for that purpose is declining. According to the city of Toronto, for example, only two of the seven tree species occurring most frequently in the city were non-native in 2014. While only 50% of the estimated 11.5 million trees are native; (City of Toronto, 2018), the proportion of native species is gradually increasing because current planting policy aims to replace invasive exotics with large-growing native hardwood species.

Table 4.2 Native species of Canada (from Canada's 2012 FGR Report).

Genus	Common names	No. of species	Species
Gymnosperms			
Abies	Fir	4	*A. amabilis, A. balsamea, A. grandis, A. lasiocarpa*
Callitropsis	Cypress	1	*C. nootkatensis*
Juniperus	Juniper	2	*J. virginiana, J. scopulorum*
Larix	Larch	3	*L. laricina, L. lyallii, L. occidentalis*
Picea	Spruce	5	*P. engelmannii, P. glauca, P. mariana, P. rubens, P. sitchensis*
Pinus	Pine	9	*P. albicaulis, P. banksiana, P. contorta, P. flexilis, P. monticola, P. ponderosa, P. resinosa, P. rigida, P. strobus*

Genus	Common names	No. of species	Species
Pseudotsuga	Douglas-fir	1	*P. menziesii* (var. *menziesii*, var. *glauca*)
Taxus	Yew	1	*T. brevifolia*
Thuja	Cedar	2	*T. occidentalis*, *T. plicata*
Tsuga	Hemlock	3	*T. canadensis*, *T. heterophylla, T. mertensiana*
Summary:	10 genera; 31 species		
Angiosperms			
Acer	Maple	10	*A. circinatum, A. glabrum, A. macrophyllum, A. negundo* (var. *negundo*, var. *violaceumII*), *A. nigrum, A. rubrum, A. pensylvanicum, A. saccharinum, A. saccharum, A. spicatum*
Aesculus	Buckeye	1	*A. glabra*
Alnus	Alder	4	*A. rubra, A. rugosa,* (syn. *incana* ssp. *rugosa*), *A. sinuata* (syn. *viridis* ssp. *sinuate*), *A. incana* ssp. *tenuifolia* (syn. *tenuifolia*)
Arbutus	Arbutus	1	*A. menziesii*
Asimina	Pawpaw	1	*A. triloba*
Betula	Birch	8	*B. alleghaniensis*, *B. cordifolia*, *B. lenta*, *B. lutea, B. neoalaskana* (syn. *pendula*), *B. occidentalis*, *B. papyrifera* (var. *cordifolia*), *B. populifolia*
Carpinus	Blue Beech	1	*C. caroliniana*
Carya	Hickory	4	*C. cordiformis, C. glabra* (var. *odorata*), *C. laciniosa*, *C. ovata*
Castanea	Chestnut	1	*C. dentata*
Celtis	Hackberry	1	*C. occidentalis*
Cercis	Redbud	1	*C. canadensis*[1]
Cornus	Dogwood	3	*C. alternifolia*, *C. florida, C. nuttallii*
Crataegus	Hawthorns	4	*C. crus-galli*, *C. coccinea*, *C. douglasii, C. mollis*
Fagus	Beech	1	*F. grandifolia*
Fraxinus	Ash	5	*F. americana*, *F. nigra*, *F. pennsylvanica*, *F. profunda, F. quadrangulata*
Gleditsia	Honey Locust	1	*G. triacanthos*
Gymnocladus	Kentucky Coffee-Tree	1	*G. dioicus*
Hamamelis	Witch Hazel	1	*H. virginiana*
Juglans	Walnut	2	*J. cinerea, J. nigra*
Liriodendron	Tulip Tree	1	*L. tulipifera*
Magnolia	Cucumber Tree	1	*M. acuminata*
Malus	Wild Apple	2	*M. coronaria, M. fusca*
Morus	Mulberry	1	*M. rubra*
Nyssa	Black Gum	1	*N. sylvatica*

Genus	Common names	No. of species	Species
Ostrya	Ironwood	1	*O. virginiana*
Platanus	Sycamore	1	*P. occidentalis*
Populus	Poplar	6	*P. angustifolia*, *P. balsamifera*, *P. deltoids* [var. *deltoids*, var. *occidentalis*], *P. grandidentata*, *P. tremuloides, P. trichocarpa*
Prunus	Cherry	6	*P. americana, P. emarginata, P. nigra*, *P. pensylvanica*, *P. serotina*, *P. virginiana* [var. *virginiana*]
Ptelea	Hop-tree	1	*P. trifoliata*
Quercus	Oak	11	*Q. alba*, *Q. bicolor*, *Q. ellipsoidalis*, *Q. garryana*, *Q. macrocarpa*, *Q. muehlenbergii*, *Q. palustris*, *Q. prinoides*, *Q. rubra*, *Q. shumardii*, *Q. velutina*
Frangula	Buckthorn	1	*F. purshiana*
Salix	Willow (trees only)	2	S. *amygdaloides*, S. *nigra*
Sambucus	Elder	2	S. *cerulea,* S. *glauca*
Sassafras	Sassafras	1	S. *albidum*
Sorbus	Mountain Ash	2	S. *americana,* S. *decora*
Tilia	Basswood	1	*T. americana*
Ulmus	Elm	3	*U. americana*, *U. rubra*, *U. thomasii*
Summary:	37 genera; 95 species		

1. This species is most likely extirpated.

4.3. Species considered as threatened

The most comprehensive overview of the status of Canada's wild species is compiled by the program on the General Status of Species of Canada representing a collaboration of all provinces, territories and federal government ministries. The mandate of the program is to "monitor, assess and report regularly on the status of all wild species" to meet the commitment of the provincial and federal ministers responsible for wildlife in Canada, under the Accord for the Protection of Species at Risk signed in 1996. The Wild Species reports produced by this program provide updated assessments of species at risk every 5 years (Canadian Endangered Species Conservation Council, 2016). The most recent report was published in 2015 and it indicated that the majority of Canada's woody species (77%) are secure or apparently secure. Among the species judged to be at risk, 28 (7%) are vulnerable. These include two new species designations, two previously unranked species, six species that had been ranked apparently secure in 2010 and two that were ranked imperiled in 2010. Six species that had been ranked as vulnerable in 2010 were designated imperiled in 2015. The number of imperiled species was 32 (8%), including seven new species and seven species that were not previously ranked. Critically imperiled species totaled 18 (4%), including five species that were not ranked in 2010. Nine species could not be ranked due to lack of sufficient information, one is presumed extirpated, and two others may be extirpated. Most of the species at risk are shrubs.

Table 4.3 Status of tree and shrub species, and changes in status between 2010 and 2015 assessments by the program on the General Status of Species of Canada. Sixty species were determined to have changed status for one of four reasons: taxonomic changes, new knowledge, or being newly described; species previously or now unranked due to lack of data; increased risk, and; reduced risk. Thirteen species were noted to have increased risk, most of which are shrubs, and seven had reduced risk. The only tree species that received a higher threat designation in 2015 than previously is blue ash (*Fraxinus quadrangulata*), which was changed from vulnerable to imperiled.

Table 4.3. Wild species national average status ranks 2010 and 2015 adapted from Regional to National General Status Assessments (Canadian Endangered Species Conservation Council, 2016). National ranks are coded as follows: X (presumed extirpated); H (possibly extirpated); 1 (critically imperiled; 2 (imperiled); 3 (vulnerable); 4 (apparently secure); 5 (secure); U (unrankable); NR (not ranked); NA (not applicable). Reasons for status changes are coded as follows: B (biological change in the population size, distribution, or threats of the species); C (COSEWIC assessment); E (error in previous rank); I (improved knowledge of the species); P (procedural change); T (taxonomic change).

Species (2015)	Rounded National Rank (2010)	Rounded National Rank (2015)	Description of change (2015)	Reason for change (2015)
Abies amabilis	N5	N5		
Abies balsamea	N5	N5		
Abies bifolia	N5	N5		
Abies grandis	N5	N5		
Abies lasiocarpa	N5	N5		
Acer circinatum	N5	N5		
Acer glabrum	N5	N5		
Acer macrophyllum	N5	N5		
Acer negundo	N5	N5		
Acer nigrum	N4	N4		
Acer pensylvanicum	N5	N5		
Acer rubrum	N5	N5		
Acer saccharinum	N5	N5		
Acer saccharum	N5	N5		
Acer spicatum	N5	N5		
Aesculus glabra	N1	N1		
Alnus incana	N5	N5		

Species (2015)	Rounded National Rank (2010)	Rounded National Rank (2015)	Description of change (2015)	Reason for change (2015)
Alnus rubra	N5	N5		
Alnus serrulata	N3	N3		
Alnus viridis	N5	N5		
Amelanchier alnifolia	N5	N5		
Amelanchier amabilis		N2	New species	T - was *Amelanchier sanguinea*
Amelanchier arborea	N5	N5		
Amelanchier bartramiana	N5	N5		
Amelanchier canadensis	N4	N4		
Amelanchier cusickii		N5	New species	T - was *Amelanchier alnifolia*
Amelanchier fernaldii	NU	N3	Changed from or to U, NR, NA	I
Amelanchier gaspensis		N4	New species	T - was *Amelanchier sanguinea*
Amelanchier humilis	N5	N5		
Amelanchier interior	N5	N5		
Amelanchier intermedia		N4	New species	T - Now a verified species
Amelanchier laevis	N5	N5		
Amelanchier nantucketensis	N1	N1		
Amelanchier sanguinea	N5	N5		
Amelanchier spicata	N5	N5		
Arbutus menziesii	N4	N4		
Arctous rubra	N5	N5		
Atriplex canescens	N4	N3	Increased level of risk	P
Betula alleghaniensis	N5	N5		
Betula cordifolia	N5	N5		
Betula glandulosa	N5	N5		
Betula kenaica	NU	NU		
Betula lenta	N1	N1		
Betula michauxii	N5	N5		

Species (2015)	Rounded National Rank (2010)	Rounded National Rank (2015)	Description of change (2015)	Reason for change (2015)
Betula minor	N4	N4		
Betula murrayana		NH	New species	I
Betula nana	N5	N5		
Betula neoalaskana (syn. *pendula*)	N5	N5		
Betula occidentalis	N5	N5		
Betula papyrifera	N5	N5		
Betula populifolia	N5	N5		
Betula pumila	N5	N5		
Carpinus caroliniana	N5	N5		
Carya cordiformis	N5	N5		
Carya glabra	N3	N3		
Carya laciniosa	N3	N3		
Carya ovata	N5	N5		
Castanea dentata	N1	N1		
Ceanothus americanus	N4	N4		
Ceanothus herbaceus	N4	N4		
Ceanothus sanguineus	N5	N5		
Ceanothus velutinus	N5	N5		
Celastrus scandens	N5	N5		
Celtis occidentalis	N4	N4		
Celtis tenuifolia	N2	N2		
Cephalanthus occidentalis	N5	N5		
Cornus alternifolia	N5	N5		
Cornus drummondii	N4	N4		
Cornus florida	N1	N2	Reduced level of risk	P
Cornus nuttallii	N5	N5		
Cornus obliqua	N5	N5		
Cornus racemosa	N5	N5		
Cornus rugosa	N5	N5		
Cornus stolonifera	N5	N5		
Cornus suecica	N5	N5		
Cornus unalaschkensis	N5	N5		
Corylus americana	N5	N5		
Corylus cornuta	N5	N5		
Crataegus aquacervensis	NU	N2	Changed from or to U, NR, NA	I

Species (2015)	Rounded National Rank (2010)	Rounded National Rank (2015)	Description of change (2015)	Reason for change (2015)
Crataegus atrovirens		N2	New species	I - Described recently
Crataegus beata	N1	N1		
Crataegus brainerdii	N2	N2		
Crataegus calpodendron	N4	N4		
Crataegus castlegarensis	NU	N4	Changed from or to U, NR, NA	I
Crataegus chrysocarpa	N5	N5		
Crataegus coccinea	N5	N5		
Crataegus coccinioides	NU	N2	Changed from or to U, NR, NA	I
Crataegus cognata		NU	New species	T - was *Crataegus pruinosa*
Crataegus compacta	N4	N4		
Crataegus crus-galli	N4	N4		
Crataegus cupressocollina	NU	N1	Changed from or to U, NR, NA	I
Crataegus dodgei	N4	N4		
Crataegus douglasii	N4	N4		
Crataegus enderbyensis		N2	New species	I -Described recently
Crataegus flabellata	N4	N4		
Crataegus florifera		NU	New species	I
Crataegus fluviatilis	NU	N2	Changed from or to U, NR, NA	I
Crataegus formosa		N2	New species	T - Previously Crataegus pruinosa
Crataegus gaylussacia	N4	N4		
Crataegus holmesiana	N4	N4		
Crataegus intricata	N1	NH	Increased level of risk	I
Crataegus irrasa	N4	N4		
Crataegus jonesiae	NU	NU		
Crataegus knieskerniana	NU	NU		
Crataegus lemingtonensis	NU	NU		

Species (2015)	Rounded National Rank (2010)	Rounded National Rank (2015)	Description of change (2015)	Reason for change (2015)
Crataegus lumaria	N3	N2	Increased level of risk	P
Crataegus macracantha		N5	New species	I
Crataegus macrosperma	N5	N5		
Crataegus magniflora	NU	N3	Changed from or to U, NR, NA	T
Crataegus margarettae	N1	N1		
Crataegus mollis	N4	N4		
Crataegus okanaganensis		N3	New species	I
Crataegus okennonii		N3	New species	I
Crataegus orbicularis		N2	New species	I - Described recently
Crataegus pennsylvanica		NU	New species	I
Crataegus perjucunda	NU	N1	Changed from or to U, NR, NA	I
Crataegus persimilis	NU	N1	Changed from or to U, NR, NA	I
Crataegus phippsii		N2	New species	I
Crataegus populnea	NU	N4	Changed from or to U, NR, NA	I
Crataegus pruinosa	N5	N5		
Crataegus punctata	N5	N5		
Crataegus rivuloadamensis	NU	N2	Changed from or to U, NR, NA	I
Crataegus rivulopugnensis	NU	N1	Changed from or to U, NR, NA	I
Crataegus rubribracteolata	NU	N2	Changed from or to U, NR, NA	I
Crataegus scabrida	N4	N4		
Crataegus schuettei	N4	N4		
Crataegus sheila-phippsiae	NU	N2	Changed from or to U, NR, NA	I
Crataegus sheridana	NU	N2	Changed from or to U, NR, NA	I
Crataegus shuswapensis		N2	New species	I - Described recently

Species (2015)	Rounded National Rank (2010)	Rounded National Rank (2015)	Description of change (2015)	Reason for change (2015)
Crataegus stolonifera		NU	New species	I
Crataegus submollis	N5	N5		
Crataegus suborbiculata	N2	N2		
Crataegus succulenta	N5	N5		
Crataegus ursopedensis	NU	N1	Changed from or to U, NR, NA	I
Diervilla lonicera	N5	N5		
Dirca palustris	N4	N4		
Elaeagnus commutata	N5	N5		
Fagus grandifolia	N5	N5		
Fraxinus americana	N5	N5		
Fraxinus latifolia	N1	N1		
Fraxinus nigra	N5	N5		
Fraxinus pennsylvanica	N5	N5		
Fraxinus profunda	N2	N2		
Fraxinus quadrangulata	N3	N2	Increased level of risk	P
Gleditsia triacanthos	N2	N2		
Gymnocladus dioicus	N2	N2		
Hamamelis virginiana	N5	N5		
Ilex glabra	N5	N5		
Ilex mucronata	N5	N5		
Ilex verticillata	N5	N5		
Juglans cinerea	N1	N1		
Juglans nigra	N4	N4		
Juniperus communis	N5	N5		
Juniperus horizontalis	N5	N5		
Juniperus maritima	N3	N3		
Juniperus scopulorum	N4	N4		
Juniperus virginiana	N5	N5		
Kalmia angustifolia	N5	N5		
Kalmia microphylla	N4	N4		
Kalmia polifolia	N5	N5		
Kalmia procumbens	N4	N4		
Larix laricina	N5	N5		
Larix lyallii	N5	N5		
Larix occidentalis	N5	N5		
Liriodendron tulipifera	N4	N4		

Species (2015)	Rounded National Rank (2010)	Rounded National Rank (2015)	Description of change (2015)	Reason for change (2015)
Lonicera canadensis	N5	N5		
Lonicera ciliosa	N5	N5		
Lonicera dioica	N5	N5		
Lonicera hirsuta	N5	N5		
Lonicera hispidula	N5	N5		
Lonicera involucrata	N5	N5		
Lonicera oblongifolia	N5	N5		
Lonicera utahensis	N5	N5		
Lonicera villosa	N5	N5		
Magnolia acuminata	N2	N2		
Malus coronaria	N4	N4		
Malus fusca	N5	N5		
Morella californica	N3	N3		
Morella pensylvanica	N5	N5		
Morus rubra	N2	N2		
Myrica gale	N5	N5		
Nyssa sylvatica	N3	N3		
Ostrya virginiana	N5	N5		
Paxistima myrsinites	N5	N5		
Penstemon fruticosus	N5	N5		
Philadelphus lewisii	N5	N5		
Physocarpus malvaceus	N5	N5		
Picea engelmannii	N5	N5		
Picea glauca	N5	N5		
Picea mariana	N5	N5		
Picea rubens	N5	N5		
Picea sitchensis	N5	N5		
Pinus albicaulis	N3	N3		
Pinus banksiana	N5	N5		
Pinus contorta	N5	N5		
Pinus flexilis	N3	N3		
Pinus monticola	N4	N4		
Pinus ponderosa	N5	N5		
Pinus resinosa	N5	N5		
Pinus rigida	N2	N2		
Pinus strobus	N5	N5		
Populus angustifolia	N3	N3		
Populus balsamifera	N5	N5		

Species (2015)	Rounded National Rank (2010)	Rounded National Rank (2015)	Description of change (2015)	Reason for change (2015)
Populus deltoides	N5	N5		
Populus grandidentata	N5	N5		
Populus heterophylla	N1	N1		
Populus tremuloides	N5	N5		
Populus trichocarpa		N5	New species	T - was Populus balsamifera
Prunus americana	N4	N4		
Prunus emarginata	N5	N5		
Prunus nigra	N4	N4		
Prunus pensylvanica	N5	N5		
Prunus pumila	N4	N4		
Prunus serotina	N5	N5		
Prunus virginiana	N5	N5		
Ptelea trifoliata	N2	N3	Reduced level of risk	I
Quercus alba	N5	N5		
Quercus bicolor	N4	N4		
Quercus ellipsoidalis	N3	N3		
Quercus garryana	N5	N5		
Quercus ilicifolia	N1	N1		
Quercus macrocarpa	N5	N5		
Quercus muehlenbergii	N4	N4		
Quercus palustris	N4	N4		
Quercus prinoides	N2	N2		
Quercus rubra	N5	N5		
Quercus shumardii	N3	N3		
Quercus velutina	N4	N4		
Rhamnus alnifolia	N5	N5		
Rhododendron albiflorum	N5	N5		
Rhododendron canadense	N5	N5		
Rhododendron groenlandicum	N5	N5		
Rhododendron lapponicum	N5	N5		
Rhododendron macrophyllum	N4	N3	Increased level of risk	P

Species (2015)	Rounded National Rank (2010)	Rounded National Rank (2015)	Description of change (2015)	Reason for change (2015)
Rhododendron maximum	NX	NX		
Rhododendron neoglandulosum	N4	N3	Increased level of risk	P
Rhododendron tomentosum	N5	N5		
Rhus aromatica	N5	N5		
Rhus copallinum	N4	N4		
Rhus glabra	N5	N5		
Rhus typhina	N5	N5		
Ribes acerifolium	N3	N4	Reduced level of risk	I
Ribes americanum	N5	N5		
Ribes aureum	N4	N3	Increased level of risk	P
Ribes bracteosum	N5	N5		
Ribes cereum	N5	N5		
Ribes cynosbati	N5	N5		
Ribes divaricatum	N5	N5		
Ribes glandulosum	N5	N5		
Ribes hirtellum	N5	N5		
Ribes hudsonianum	N5	N5		
Ribes inerme	N4	N4		
Ribes lacustre	N5	N5		
Ribes laxiflorum	N5	N5		
Ribes lobbii	N4	N4		
Ribes oxyacanthoides	N5	N5		
Ribes sanguineum	N5	N5		
Ribes triste	N5	N5		
Ribes viscosissimum	N5	N5		
Ribes watsonianum		NU	New species	I
Rosa acicularis	N5	N5		
Rosa arkansana	N5	N5		
Rosa blanda	N5	N5		
Rosa carolina	N4	N4		
Rosa gymnocarpa	N5	N5		
Rosa nitida	N5	N5		
Rosa nutkana	N5	N5		
Rosa palustris	N5	N5		

Species (2015)	Rounded National Rank (2010)	Rounded National Rank (2015)	Description of change (2015)	Reason for change (2015)
Rosa pisocarpa	N4	N4		
Rosa setigera	N3	N2	Increased level of risk	P
Rosa virginiana	N5	N5		
Rosa woodsii	N5	N5		
Salix alaxensis	N5	N5		
Salix amygdaloides	N5	N5		
Salix arbusculoides	N5	N5		
Salix arctica	N5	N5		
Salix arctophila	N5	N5		
Salix argyrocarpa	N5	N5		
Salix athabascensis	N4	N4		
Salix ballii	N4	N3	Increased level of risk	P
Salix barclayi	N5	N5		
Salix barrattiana	N5	N5		
Salix bebbiana	N5	N5		
Salix boothii	N4	N3	Increased level of risk	P
Salix brachycarpa	N5	N5		
Salix calcicola	N4	N4		
Salix candida	N5	N5		
Salix cascadensis	N3	N5	Reduced level of risk	I
Salix chamissonis	N3	N4	Reduced level of risk	I
Salix chlorolepis	N1	N1		
Salix commutata	N5	N5		
Salix cordata	N4	N4		
Salix discolor	N5	N5		
Salix drummondiana	N5	N5		
Salix eriocephala	N5	N5		
Salix exigua	N5	N5		
Salix famelica	N4	N4		
Salix farriae	N4	N4		
Salix fuscescens	N5	N5		
Salix geyeriana	N3	N5	Reduced level of risk	I
Salix glauca	N5	N5		

Species (2015)	Rounded National Rank (2010)	Rounded National Rank (2015)	Description of change (2015)	Reason for change (2015)
Salix hastata	N5	N5		
Salix herbacea	N5	N5		
Salix hookeriana	N5	N5		
Salix humilis	N5	N5		
Salix interior	N5	N5		
Salix jejuna	N1	N1		
Salix lasiandra	N5	N5		
Salix lucida	N5	N5		
Salix maccalliana	N5	N5		
Salix melanopsis	N4	N4		
Salix myricoides	N4	N4		
Salix myrtillifolia	N5	N5		
Salix nigra	N4	N4		
Salix niphoclada	N5	N5		
Salix nivalis	N5	N5		
Salix ovalifolia	N3	N3		
Salix pedicellaris	N5	N5		
Salix pellita	N5	N5		
Salix petiolaris	N5	N5		
Salix petrophila	N5	N5		
Salix phlebophylla	N4	N4		
Salix planifolia	N5	N5		
Salix polaris	N5	N5		
Salix prolixa	N5	N5		
Salix pseudomonticola	N5	N5		
Salix pseudomyrsinites	N5	N5		
Salix pulchra	N5	N5		
Salix pyrifolia	N5	N5		
Salix raupii	N2	N3	Reduced level of risk	P
Salix reticulata	N5	N5		
Salix richardsonii	N5	N5		
Salix rotundifolia	N4	N4		
Salix scouleriana	N5	N5		
Salix sericea	N5	N5		
Salix serissima	N5	N5		
Salix sessilifolia	N3	N3		
Salix setchelliana	N3	N3		

Species (2015)	**Rounded National Rank (2010)**	**Rounded National Rank (2015)**	**Description of change (2015)**	**Reason for change (2015)**
Salix silicicola	N3	N2	Increased level of risk	P
Salix sitchensis	N5	N5		
Salix sphenophylla	N2	N2		
Salix stolonifera	N5	N5		
Salix turnorii	N3	N2	Increased level of risk	P
Salix tweedyi	N3	N3		
Salix tyrrellii	N3	N2	Increased level of risk	P
Salix uva-ursi	N5	N5		
Salix vestita	N5	N5		
Sambucus canadensis		N5	New species	T - was *Sambucus nigra*
Sambucus nigra	N5	N5		
Sambucus racemosa	N5	N5		
Shepherdia argentea	N4	N4		
Shepherdia canadensis	N5	N5		
Sorbus americana	N5	N5		
Sorbus decora	N5	N5		
Sorbus scopulina	N5	N5		
Sorbus sitchensis	N5	N5		
Spiraea alba	N5	N5		
Spiraea douglasii	N5	N5		
Spiraea latifolia	NU	N5	Changed from or to U, NR, NA	T
Spiraea lucida		N5	New species	T - was *Spiraea betulifolia*
Spiraea splendens	N3	N3		
Spiraea stevenii	N5	N5		
Spiraea tomentosa	N5	N5		
Taxus brevifolia	N5	N5		
Taxus canadensis	N5	N5		
Thuja occidentalis	N5	N5		
Thuja plicata	N5	N5		
Tilia americana	N5	N5		
Tsuga canadensis	N5	N5		
Tsuga heterophylla	N5	N5		
Tsuga mertensiana	N5	N5		

Species (2015)	Rounded National Rank (2010)	Rounded National Rank (2015)	Description of change (2015)	Reason for change (2015)
Ulmus americana	N5	N5		
Ulmus rubra	N5	N5		
Ulmus thomasii	N4	N4		
Vaccinium angustifolium	N5	N5		
Vaccinium boreale	N4	N4		
Vaccinium caespitosum	N5	N5		
Vaccinium corymbosum	N4	N4		
Vaccinium deliciosum	N5	N5		
Vaccinium macrocarpon	N5	N5		
Vaccinium membranaceum	N5	N5		
Vaccinium microcarpum		N4	New species	T
Vaccinium myrtilloides	N5	N5		
Vaccinium myrtillus	N5	N5		
Vaccinium ovalifolium	N5	N5		
Vaccinium ovatum	N4	N4		
Vaccinium oxycoccos	N5	N5		
Vaccinium pallidum	N4	N4		
Vaccinium parvifolium	N5	N5		
Vaccinium scoparium	N5	N5		
Vaccinium stamineum	N1	N1		
Vaccinium uliginosum	N5	N5		
Vaccinium vitis-idaea	N5	N5		
Viburnum acerifolium	N5	N5		
Viburnum edule	N5	N5		
Viburnum lantanoides	N5	N5		
Viburnum lentago	N5	N5		
Viburnum nudum	N5	N5		
Viburnum opulus	N5	N5		
Viburnum rafinesquianum	N5	N5		
Viburnum recognitum	N4	N4		

At the federal level, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) operates as an independent body comprised of wildlife experts and scientists who identify species at risk and designate the conservation status. Species that are designated by COSEWIC are then assessed for inclusion on the Species at Risk Registry for legal protection under the Species at Risk Act (SARA). Table 4.4 lists the tree species that have a federal risk designation. Since the last national report was prepared, *Pinus flexilis* has been added, designated endangered, but it has not yet been added to the SARA registry for legal protection. *Fraxinus nigra* has received a SARA ranking of threatened during this reporting period. There are no other changes to tree species designations.

Table 4.4 Tree species with official federal risk designation based on the *Species at Risk Act* (SARA).

Species at Risk	COSEWIC Ranking	SARA Ranking[1]	Jurisdiction identified as being at risk	Species' Natural Range in Canada
Betula lenta	Endangered	Endangered	Ontario	Ontario
Juglans cinerea	Endangered	Endangered	Ontario	Ontario, Quebec, New Brunswick
Castanea dentata	Endangered	Endangered	Ontario	Ontario
Cornus florida	Endangered	Endangered	Ontario	Ontario
Morus rubra	Endangered	Endangered	Ontario	Ontario
Pinus albicaulis	Endangered	No Status Assigned	British Columbia, Alberta	British Columbia, Alberta
Pinus flexilis	Endangered (2014)	No status assigned	Alberta	British Columbia, Alberta
Magnolia acuminata	Endangered	Endangered	Ontario	Ontario
Gymnocladus dioicus	Threatened	Threatened	Ontario	Ontario
Ptelea trifoliata	Threatened, Special Concern	Special Concern	Ontario	Ontario
Fraxinus quadrangulata	Special Concern	Special Concern	Ontario	Ontario
Fraxinus nigra	Threatened (2018)	No status assigned	Nova Scotia	Manitoba, east
Quercus shumardii	Special Concern	Special Concern	Ontario	Ontario

1. Data collected from Species at risk registry - http://www.sararegistry.gc.ca/sar/index/default_e.cfm Accessed March 2020 and the Minister of Environment's response to species at risk assessments submitted by COSEWIC on October 9, 2019 (https://www.canada.ca/en/environment-climate-change/services/species-risk-act-

accord-funding/listing-process/minister-environment-response-assessments-2019.html) accessed July 2020

Tree species of concern were identified by the CONFORGEN survey (Beardmore, et al. 2006) and were listed in Canada's 2012 FGR Report. The survey has not been updated.

4.4. Trends in the number of species

The number of species in Canada is approximately stable. By far the greatest source of variation in number of species is through introduction of exotics. The Wild Species Program reported that in 2015, 1315 vascular plant species—representing 25% of all species of vascular plants in Canada—were exotic (Canadian Endangered Species Conservation Council, 2016). The vast majority of these species are herbaceous. This count represents a slight increase compared to 2010, when approximately 1,229 (24%) of the 5,087 known plants were reported to be exotic (Canada's National Biodiversity Clearing House, accessed April, 2020).

4.5. Drivers of change affecting species at risk

The most serious drivers of change affecting species at risk in Canada are: habitat loss and degradation as a result of human intrusion for recreation, residential and commercial development, and agriculture; introduced insect pests, diseases, and other invasive species, and; environmental impacts of changing climate and pollution (McCune and Morrison, 2020; McCune *et al.*, 2013).

McCune (2020) noted that most plant species at risk do not benefit from the protection afforded by SARA because that framework applies only to federally owned land, whereas most plant species at risk occur primarily on private land. As a result, there is a pressing need for the federal government to promote stewardship of plant species at risk on private lands.

Literature Cited

Almas, A.D. and Conway, T.M., 2016. The role of native species in urban forest planning and practice: A case study of Carolinian Canada. Urban forestry & urban greening, 17, pp. 54-62.

Beardmore, T., Loo, J., McAfee, B., Malouin, C. and Simpson, D., 2006. A survey of tree species of concern in Canada: the role for genetic conservation. The Forestry Chronicle, 82(3), pp.351-363.Canadian Endangered Species Conservation Council. 2016. Wild Species 2015: The General Status of Species in Canada. National General Status Working Group.

Canadian Endangered Species Conservation Council. 2016. Wild Species 2015: The General Status of Species in Canada. National General Status Working Group: 128 pp.

Canada's National Biodiversity Clearing House. https://biodivcanada.chm-cbd.net/ecosystem-status-trends-2010/invasive-non-native-species

City of Toronto. 2018. Tree canopy study. https://www.toronto.ca/services-payments/water-environment/trees/

Farrar, J.L. 1995. Trees in Canada. Natural Resources Canada, Canadian Forest Service, Ottawa, Co-published by Fitzhenry and Whiteside Limited, Markham, Ontario. 502 p.

Fowler, D.P. and Coles, J.F., 1980. Norway spruce provenance experiments in the Maritimes region of Canada. The Forestry Chronicle, 56(4), pp.155-160.

Fraser, E., Marenholtz, E., Sobze, J.M., Schoonmaker, A., Mckenzie, M., Smreciu, A. and Powter, C.B., 2014. Alternative Native Boreal Seed and Plant Delivery Systems for Oil Sands Reclamation. Oil Sands Research and Information Network, University of Alberta, School of Energy and the Environment, Edmonton, Alberta. OSRIN Report No. TR-55. 61 pp.

Holst, M.J. and Heimburger, C.C., 1969. Tree breeding and genetics of exotic conifers in Canada. The Forestry Chronicle, 45(6), pp.434-440.McCune, J.L. and Morrison, P.D., 2020. Conserving plant species at risk in Canada: land tenure, threats, and representation in federal programs. FACETS, 5(1), pp.538-550.

McCune, J.L. and Morrison, P.D.S. 2020. Conserving plant species at risk in Canada: land tenure, threats, and representation in federal programs. Facets 5(1):

McCune, J.L., Harrower, W.L., Avery-Gomm, S., Brogan, J.M., Csergő, A.M., Davidson, L.N., Garani, A., Halpin, L.R., Lipsen, L.P., Lee, C. and Nelson, J.C., 2013. Threats to Canadian species at risk: an analysis of finalized recovery strategies. Biological Conservation, 166, pp.254-265.

Natural Resources Canada. 2019. Atlas of Canada 6th Edition, 1999 – 2009 (archival version). https://www.nrcan.gc.ca/maps-tools-publications/tools/geodetic-reference-systems/forest-maps/16874

Chapter 5. State of genetic diversity within trees and other woody plants species

Genetic diversity of boreal and northern temperate tree species tends to be high because most are wind-pollinated and occupy large continuous areas. With the possible exception of a few tree species that reach their northern limit at Canada's southern border, there is no evidence of serious genetic erosion of any tree species in Canada. A survey of the literature reveals that at least 43 genetic diversity studies have been carried out since the last report was written, describing genetic diversity for part or all of the range of 27 native tree species (Table 5.1).

Canada does not have a central repository for forest genetic resources (FGR) data, but research groups in various jurisdictions maintain genetic data obtained for the tree species of importance in their area. At least 13 studies carried out since 2012 on 10 tree species contributed to knowledge of patterns of geographic variation. Numerous studies have been carried out to characterize the genetic resources of forest trees, but little, if any, regular monitoring has been done, which means that trends in genetic diversity are difficult to estimate. Surrogate measures, such as size and fragmentation of populations of selected tree species, are more common.

5.1. Actions that have been, or are being taken, for assessing and analysing the genetic diversity of trees and other wooded plant species

Canada does not have a coordinated national approach for assessing and analyzing the genetic diversity of trees or other woody species. Research groups, combining expertise from universities and both provincial and federal government, have come together to increase the understanding of genetic resources of important tree species, but this effort has been limited primarily to British Columbia, Alberta, and Quebec.

The number of universities conducting research on tree genetic resources has expanded beyond traditional forestry schools: in British Columbia, in addition to research carried out at the University of British Columbia and University of Northern British Columbia, Simon Fraser and the University of Victoria produce graduate studies on genetic diversity in trees; in Alberta, tree genetics research is carried out at Concordia University of Edmonton as well as the University of Alberta; Ontario's Lakehead, Carleton, Guelph and Trent, and Laurentian Universities supported research on tree genetics in the past eight years; genetic studies on trees are conducted at Laval University in Quebec and at the University of New Brunswick in the Maritime provinces.

Table 5.1 Survey of the scientific literature assessing intraspecific variation of native tree species in Canada, 1987-2020. The dates of articles published since 2012 are in bold.

Species	Research paper title and citation	Method for analyzing intraspecific variation
Acer saccharum	• Allozyme variation in sugar maple at the northern limit of its range in Ontario, Canada. (Perry and Knowles 1989)	• Allozyme marker

Species	Research paper title and citation	Method for analyzing intraspecific variation
	• Genetic variation and structure at three spatial scales for *Acer saccharum* (sugar maple) in Canada and the implications for conservation. (Young *et al.* 1993)	• Allozyme marker
	• Influence of northern limit range on genetic diversity and structure in a widespread North American tree, sugar maple (*Acer saccharum* Marshall). (Graignic *et al.*, 2018)	• Microsatellite marker
	• Geographical variation in reproductive capacity of sugar maple (*Acer saccharum* Marshall) northern peripheral populations. (Graignic *et al.*, 2014)	• Seedling recruitment
	• Development of polymorphic nuclear microsatellite markers in sugar maple (*Acer saccharum* Marsh.) using cross-species transfer and SSR-enriched shotgun pyrosequencing. (Graignic *et al.* 2013)	• Microsatellite marker
	• Genetic consequences of selection cutting on sugar maple (*Acer saccharum* Marshall). (Graignic *et al.* 2016)	• Microsatellite marker
Acer rubrum	• Molecular analysis of red maple (*Acer rubrum*) populations from a reclaimed mining region in Northern Ontario (Canada): soil metal accumulation and translocation in plants. (Kalubi *et al.* 2015)	• ISSR marker
Acer negundo	• Genetic differentiation and phenotypic plasticity in life-history traits between native and introduced populations of invasive maple trees. (Lamarque *et al.* 2015)	• Phenotype
Alnus crispa	• Genetic differentiation among 22 mature populations of green alder (*Alnus crispa*) in central Quebec. (Bousquet *et al.* 1987b)	• Allozyme marker
	• Genetic diversity within and among 11 juvenile populations of green alder (*Alnus crispa*) in Canada. (Bousquet *et al.* 1987c)	• Allozyme marker
	• Allozyme variability in natural populations of green alder (*Alnus crispa*) in Quebec. (Bousquet *et al.* 1987a)	• Allozyme marker
	• Allozyme variation within and among mature populations of speckled alder (*Alnus rugosa*) and relationships with green alder (*Alnus crispa*). (Bousquet *et al.* 1988)	• Allozyme marker

Species	Research paper title and citation	Method for analyzing intraspecific variation
Alnus rubra	• Genetics of red alder (*Alnus rubra* Bong.) populations in British Columbia and its implications for gene resources management. (Xie *et al*. 2002)	• Allozyme marker
	• Characterization of chloroplast genomes of *Alnus rubra* and *Betula cordifolia*, and their use in phylogenetic analyses in Betulaceae. (Lee *et al*., 2019)	• Whole-genome sequencing
	• Adaptive variation in growth, phenology, cold tolerance and nitrogen fixation of red alder (*Alnus rubra* Bong.). (Porter *et al.* 2013)	• Growth, phenology, cold tolerance
Arbutus menziesii	• Genetic structure and mating system of northern *Arbutus menziesii* populations. (Beland *et al*. 2005)	• AFLP marker
Betula papyrifera	• Genetic and metal analyses of fragmented populations of *Betula papyrifera* (Marsh) in a mining reclaimed region: identification of population–diagnostic molecular marker. (Theriault *et al.* 2014)	• ISSR marker
	• Molecular and ecological characterization of plant populations from limed and metal-contaminated sites in Northern Ontario (Canada): ISSR analysis of white birch (*Betula papyrifera*) populations. (Theriault *et al.* 2013)	• ISSR marker
	• Variability in height growth, survival and nursery carryover effect of *Betula papyrifera* provenances. (Dhar *et al*. 2014)	• Phenotype
	• Assessing effects of seed source and transfer potential of white birch populations using transfer functions (Oke and Wang, 2013)	• Phenotype
Callitropsis nootkatensis	• Geographic variation and adaptation to current and future climates of *Callitropsis nootkatensis* populations. (Russell and Krakowski, 2012)	• Phenotype
Crataegus spp.	• Fine-scale comparisons of genetic variability in seed families of asexually and sexually reproducing *Crataegus (*Hawthorn; *Rosaceae*). (Lo *et al.* 2010)	• Microsatellite marker
Fagus grandifolia	• Regional differentiation in genetic components for the American beech, *Fagus grandifolia* Ehrh, in relation to geological history and mode of reproduction. (Kitamura and Kawan, 2001)	• Isozyme marker
Juglans cinerea	• Low genetic diversity at allozyme loci in *Juglans cinerea*. (Morin *et al*. 2000)	• Allozyme marker

Species	Research paper title and citation	Method for analyzing intraspecific variation
	• Genetic diversity of butternut (*Juglans cinerea*) and implications for conservation. (Ross-Davis *et al*. 2008)	• Microsatellite marker
	• Butternut health and genetic diversity in New Brunswick, Canada. (Beardmore *et al*. 2017)	• Microsatellite marker
Larix laricina	• Patterns of allozyme variation in tamarack *Larix laricina* from northern Ontario. (Liu and Knowles 1991)	• Allozyme marker
	• The Population structure of *Larix laricina* in New Brunswick, Canada. (Ying and Morgenstern 1991)	• Allozyme marker
	• Genetic relationship among Eurasian and American *Larix* species based on allozymes. (Semerikov and Lascoux, 1999)	• Allozyme marker
Larix lyallii	• Population genomics of a timberline conifer, subalpine larch (*Larix lyallii* Parl.). (Vance, M., 2019)	• SNP marker
Larix occidentalis	• Genetic variation of western larch in British Columbia and its conservation. (Jaquish and El-Kassaby 1998)	• Allozyme marker
	• Genetic relationship among Eurasian and American *Larix* species based on allozymes. (Semerikov and Lascoux 1999)	• Allozyme marker
	• Development and characterization of microsatellite loci in western larch. (*Larix occidentalis* Nutt.) (Chen *et al.* 2009)	• Microsatellite marker
	• Estimates of genetic parameters and breeding values from western larch open-pollinated families using marker-based relationship. (Klápště *et al.* 2014)	• Microsatellite marker
Magnolia acuminata	• Conservation genetics of *Magnolia acuminata*, an endangered species in Canada: Can genetic diversity be maintained in fragmented, peripheral populations? (Budd *et al.* 2015)	• Microsatellite marker
Picea glauca	• Extensive long-distance pollen dispersal in a fragmented landscape maintains genetic diversity in white spruce. (O'Connell *et al.* 2007)	• Allozyme marker
	• Enhancing genetic mapping of complex genomes through the design of highly-multiplexed SNP arrays: application to the large and unsequenced genomes of white spruce and black spruce. (Pavy *et al.* 2008)	• SNP marker
	• Multivariate analysis of digital gene expression profiles identifies a xylem signature of the vascular	• Cloned DNA

Species	Research paper title and citation	Method for analyzing intraspecific variation
	tissue of white spruce (*Picea glauca*). (Albouyeh *et al*. 2010)	
	• QTL mapping in white spruce: gene maps and genomic regions underlying adaptive traits across pedigrees, years and environments. (Pelgas *et al*. 2011)	• SNP marker
	• Genetic and morphological structure of a spruce hybrid (*Picea sitchensis* × *P. glauca*) zone along a climatic gradient. (Hamilton and Aitken, 2013)	• Microsatellite marker, phenotype
	• Effects of silvicultural practices on genetic diversity and population structure of white spruce in Saskatchewan. (Fageria and Rajora 2014)	• Microsatellite marker
	• Effects of harvesting of increasing intensities on genetic diversity and population structure of white spruce. (Fageria and Rajora, 2013)	• Microsatellite marker
	• Scanning SNPs from a large set of expressed genes to assess the impact of artificial selection on the undomesticated genetic diversity of white spruce. (Namroud *et al.* 2012)	• SNP marker
Picea mariana	• Near-saturated and complete genetic linkage map of black spruce (*Picea mariana*). (Kang *et al*. 2010)	• AFLP marker
	• Clonal and nonclonal genetic structure of subarctic black spruce (*Picea mariana*) populations in Yukon Territory. (Viktora *et al*. 2011)	• Microsatellite marker
Picea mariana x P rubens	• Genetic variation in *Picea mariana* × *P. rubens* hybrid populations assessed with ISSR and RAPD markers. (Ramya and Kabwe 2012)	• ISSR marker, RAPD marker
Picea rubens	• Genetic diversity and population structure of red spruce (*Picea rubens*). (Hawley and Hayes 1994)	• Allozyme marker
	• Indicators of population viability in red spruce, *Picea rubens*. II. Genetic diversity, population structure, and mating behavior. (Rajora *et al.* 2000)	• Allozyme marker
Picea sitchensis	• Optimal sampling strategies for capture of genetic diversity differ between core and peripheral populations of *Picea sitchensis* (Bong.) Carr. (Gapare *et al*. 2007)	• Sequence-tagged site (STS) marker
	• Widespread ecologically-relevant genetic markers developed from association mapping of climate-related traits in Sitka spruce *(Picea sitchensis*). (Holliday *et al.* 2010)	• SNP marker

Species	Research paper title and citation	Method for analyzing intraspecific variation
	• Local adaptation at the range peripheries of Sitka spruce. (Mimura and Aitken 2010)	• Phenotype
Pinus albicaulis	• Biogeography and population genetics of whitebark pine (*Pinus albicaulis*). (Jorgensen and Hamrick 1997)	• Allozyme marker
	• Inbreeding and conservation genetics in whitebark pine. (Krakowski *et al.* 2003)	• Isozyme marker
	• Mating system and inbreeding depression in whitebark pine (*Pinus albicaulis* Engelm.). (Bower and Aitken 2007)	• Allozyme marker
Pinus banksiana	• Boreal forest provenance tests used to predict optimal growth and response to climate change. 1. Jack pine. (Thomson and Parker 2008)	• Provenance
	• Effect of interannual climate variations on radial growth of jack pine provenances in Petawawa, Ontario. (Savva *et al.* 2008)	• Provenance
	• Phylogeographic structure of jack pine *(Pinus banksiana; Pinaceae)* supports the existence of a coastal glacial refugium in northeastern North America. (Godbout *et al*. 2010)	• Minisatellite marker, Microsatellite marker
Pinus contorta var. *latifolia*	• The organization of genetic variability in central and marginal populations of lodgepole pine *Pinus contorta* spp. *latifolia.* (Yeh and Lavton 1979)	• Isozyme marker
	• Allozyme variability and evolution of lodgepole pine *Pinus contorta* var. *latifolia* and jack pine *Pinus banksiana* in Alberta Canada. (Dancik and Yeh 1983)	• Allozyme marker
	• Genetic variability among and within closely spaced populations of lodgepole pine. (Knowles 1984)	• Isozyme marker
	• Glacial vicariance in the Pacific Northwest: evidence from a lodgepole pine mitochondrial DNA minisatellite for multiple genetically distinct and widely separated refugia. (Godbout *et al*. 2008)	• Microsatellite marker
	• Climate impacts on lodgepole pine (*Pinus contorta*) radial growth in a provenance experiment. (McLane *et al*. 2011a)	• Phenotype
	• Modeling lodgepole pine radial growth relative to climate and genetics using universal growth-trend response functions. (McLane *et al.* 2011b)	• Phenotype
Pinus monticola	• Identification and characterization of the WRKY transcription factor family in *Pinus monticola*. (Donini *et al.* 2009)	• Gene sequences

Species	Research paper title and citation	Method for analyzing intraspecific variation
	• Genetic variation and population differentiation of the endochitinase gene family in *Pinus monticola*. (Liu *et al*. 2014)	• SNP marker
	• Provenance variation in western white pine (*Pinus monticola*): the impact of white pine blister rust. (King *et al.* 2018)	• Phenotype
Pinus monticola, P. strobus	• Contrasting patterns of genetic diversity across the ranges of *Pinus monticola* and *P. strobus*: A comparison between eastern and western North American postglacial colonization histories. (Nadeau *et al.* 2015)	• SNP marker
Pinus resinosa	• Genetic diversity in red pine evidence for low genetic heterozygosity. (Fowler and Morris 1977)	• Isozyme marker
	• Isozyme uniformity in populations of red pine (*Pinus resinosa*) in the Atibiti Region, Quebec. (Simon *et al*. 1986)	• Isoenzyme marker
	• Lack of allozymic variation in disjunct Newfoundland populations of red pine (*Pinus resinosa*). (Mosseler *et al*. 1991)	• Allozyme marker
	• Low levels of genetic diversity in red pine confirmed by random amplified polymorphic DNA markers. (Mosseler *et al*. 1992)	• RAPD marker
	• Chloroplast microsatellites reveal population genetic diversity in red pine, *Pinus resinosa* Ait. (Echt *et al*. 1998)	• Microsatellite marker
	• Microsatellite analysis reveals genetically distinct populations of red pine (*Pinus resinosa*, Pinaceae). (Boys *et al*. 2005)	• Microsatellite marker
	• Geographic pattern of genetic variation in *Pinus resinosa*: contact zone between descendants of glacial refugia. (Walter and Emerson 2005)	• Microsatellite marker, SSR marker
Pinus rigida	• Reproductive and genetic characteristic or rare, disjunct pitch pine populations at the northern limits of its range in Canada. (Mosseler *et al*. 2004)	• Allozyme marker
Pinus strobus	• Genetic structure and variability in *Pinus strobus* in Quebec. (Beaulieu and Simon 1994)	• Allozyme marker
	• Inheritance and linkage relationships of allozymes in *Pinus strobus* L. (Beaulieu and Simon 1994)	• Allozyme marker
	• Genetic diversity and population structure of disjunct. Newfoundland and central Ontario	• Allozyme marker

Species	Research paper title and citation	Method for analyzing intraspecific variation
	populations of eastern white pine (*Pinus strobus*). (Rajora *et al*. 1998)	
	• Genetic divergence and signatures of natural selection in marginal populations of a keystone, long-lived conifer, eastern white pine (*Pinus strobus*) from northern Ontario. (Chhatre and Rajora. 2014)	• Microsatellite marker
	• Climatic niche, ecological genetics, and impact of climate change on eastern white pine (*Pinus strobus* L.): Guidelines for land managers (Joyce and Rehfeldt, 2013)	• Landscape data
	• Post-glacial phylogeography and evolution of a wide-ranging highly-exploited keystone forest tree, eastern white pine (*Pinus strobus*) in North America: single refugium, multiple routes. (Zinck, Rajora. 2016)	• Microsatellite
Populus angustifolia	• Bud phenology and growth are subject to divergent selection across a latitudinal gradient in *Populus angustifolia* and impact adaptation across the distributional range and associated arthropods. (Evans *et al*. 2016)	• Phenotype
Populus balsamifera	• Isozyme variation in balsam poplar along a latitudinal transect in northwestern Ontario. (Farmer *et al*. 1988)	• Isozyme marker
	• Species-specific single nucleotide polymorphism markers for detecting hybridization and introgression in poplar. (Meirmans *et al.* 2007)	• SNP marker
	• An efficient single nucleotide polymorphism assay to diagnose the genomic identity of poplar species and hybrids on the Canadian prairies. (Talbot *et al*. 2011)	• SNP marker
Populus deltoides	• An efficient single nucleotide polymorphism assay to diagnose the genomic identity of poplar species and hybrids on the Canadian prairies. (Talbot *et al.* 2011)	• SNP marker
	• Going with the flow: Intraspecific variation may act as a natural ally to counterbalance the impacts of global change for the riparian species, *Populus*	• SNP marker
Populus tremuloides	• RAPD variation within and among natural populations of trembling aspen (*Populus tremuloides*) from Alberta. (Yeh *et al.* 1995)	• RAPD marker
	• Microsatellite analysis of genetic diversity in four populations of *Populus tremuloides* in Quebec. (Wyman *et al*. 2003)	• Microsatellite marker

Species	Research paper title and citation	Method for analyzing intraspecific variation
	• Quantitative-genetic variation in morphological and physiological traits within a quaking aspen (*Populus tremuloides*) population. (Kanaga *et al.* 2008)	• Phenotype
	• Genetic adaptation of aspen (*Populus tremuloides*) populations to spring risk environments: a novel remote sensing approach. (Haitao *et al.* 2010)	• Common garden experiment
	• The effects of genetic diversity, climate and defoliation events on trembling aspen growth performance across Canada. (Latutrie *et al.* 2015)	• Microsatellite marker, phenotype
Populus trichocarpa	• Ecotypic mode of regional differentiation caused by restricted gene migration: a case in black cottonwood (*Populus trichocarpa*) along the Pacific Northwest coast. (Xie *et al.* 2009)	• Phenotype
	• Ecotypic mode of regional differentiation of black cottonwood (*Populus trichocarpa*) due to restricted gene migration: further evidence from a field test on the northern coast of British Columbia. (Xie *et al.* 2012)	• Phenotype
	• Geographical and environmental gradients shape phenotypic trait variation and genetic structure in *Populus trichocarpa*. (McKown *et al.* 2014)	• SNP marker, phenotype
	• Genomic Diversity Evaluation of *Populus trichocarpa* Germplasm for Rare Variant Genetic Association Studies. (Piot *et al.* 2019)	• Whole-genome sequencing
Prunus virginiana	• Pollen limitation and reduced reproductive success are associated with local genetic effects in *Prunus virginiana*, a widely distributed self-incompatible shrub. (Suarez-Gonzalez, and Good, 2014)	• Microsatellite marker, gene sequencing
Pseudotsuga menziesii	• Enzyme variations in natural populations of Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, from British Columbia. 1. Genetic variation patterns in coastal populations. (Yeh and O'Malley 1980)	• Isozyme marker
	• Heritability, phenotypic and genetic correlations of coastal Douglas-fir (*Pseudotsuga menziesii*) wood quality traits. (Ukrainetz *et al.* 2008)	• Phenotype
Quercus garryana	• Isozyme variation and the conservation genetics of Garry oak. (Ritland *et al.* 2005)	• Isozyme marker
Quercus rubra	• High genetic variation among closely related red oak (*Quercus rubra*) populations in an ecosystem under	• RAPD marker

Species	Research paper title and citation	Method for analyzing intraspecific variation
	metal stress: analysis of gene regulation. (Makela *et al*. 2016)	
	• Heavy metal analysis in red oak (*Quercus rubra*) populations from a mining region in northern Ontario (Canada): effect of soil liming and analysis of genetic variation. (Narendrula *et al.* 2014)	• ISSR marker
Salix spp.	• Microsatellite markers of willow species and characterization of 11 polymorphic microsatellites for *Salix eriocephala* (Salicaceae), a potential native species for biomass production in Canada. (Lauron-Moreau *et al.* 2013)	• Phenotype
	• Genetic by environment interactions of two North American *Salix* species assessed for coppice yield and components of growth on three sites of varying quality. (Mosseler *et al.* 2014)	• Phenotype
	• Microsatellite markers of willow species and characterization of 11 polymorphic microsatellites for *Salix eriocephala* (Salicaceae), a potential native species for biomass production in Canada. (Lauron-Moreau *et al.* 2013)	• Microsatellite marker
	• Geo-climatic gradient shapes functional trait variations in *Salix eriocephala* Michx. (Shunmugam *et al.* 2016)	• Phenotype
Thuja occidentalis	• Allozyme variation of *Thuja occidentalis* L. in northwestern Ontario. (Perry *et al.* 1990)	• Allozyme marker
	• Sources of Allozymic variation in *Thuja occidentalis* in Southern Ontario Canada. (Mathes-Sears *et al.* 1991)	• Allozyme marker
	• Genetic structure, variability, and mating system in eastern white cedar (*Thuja occidentalis*) populations of recent origin in an agricultural landscape in southern Quebec. (Lamy *et al.* 1999)	• Isozyme marker
	• Genetic diversity and differentiation of core vs. peripheral populations of eastern white cedar, *Thuja occidentalis* (Cupressaceae). (Pandey and Rajora, 2012)	• Microsatellite marker
	• Genetic consequences of fragmentation in “arbor vitae,” eastern white cedar (*Thuja occidentalis* L.), toward the northern limit of its distribution range. (Xu *et al.* 2012)	• Microsatellite marker
Thuja plicata	• Isozyme variation of *Thuja plicata* (Cupressaceae) in British Columbia. (Yeh 1988)	• Isozyme marker

Species	Research paper title and citation	Method for analyzing intraspecific variation
	• Post-glacial colonization of western redcedar (*Thuja plicata*, Cupressaceae) revealed by microsatellite markers. (O'Connell *et al*. 2008)	• Microsatellite marker
22 western species	• Glacial refugia and modern genetic diversity of 22 western North American tree species. (Roberts, Hamann. 2015)	• Allozyme marker

5.2. Patterns in the geographical distribution of genetic diversity in trees and other woody plant species

Patterns of geographic variation have been examined and described using provenance trials that have been established for economically important forestry tree species over the past 70 years.

Long-established provenance trials have proven invaluable for estimating the effects of, and best adaptive strategies for, countering impacts of climate change. As described by O'Neill *et al*. (2008), such provenance tests reveal the effects of maladaptation associated with populations growing in different environments over many years, sampling the range of climatic extremes occurring at a given test site. A variety of approaches have been employed to model and predict effects of future climates using data from established provenance trials.

Li *et al*. (2020) found that, under warmer conditions, northern-most *Picea rubens* provenances experienced faster growth. Between 1978 and 1985, a series of *Picea glauca* provenance trials was established in eastern Canada (Lu *et al*. 2014). Lu *et al*. found that the southern-most provenances not only performed much better, in terms of survival and growth, in southern locations than the central or northern provenances, but continued to out-perform the more northern provenances throughout most of the range, showing no signs of frost damage. Only at the northern-most test site did the northern provenances match the performance of southern-most provenances. Yang *et al.* (2015) examined re-measurement results from provenance trials of *Picea mariana*, established in 1970, and *Pinus strobus*, established in the 1950s-60s. They determined that local provenances are suboptimal for planting in both species and that the optimal provenance was located in areas 1.5 degrees warmer than a given planting site. Several studies have been carried out on re-measurements of *Pinus contorta* provenance trials, including a range-wide trial established by Illingworth in 1974 (McLane *et al*. 2011a, 2011b, O'Neill *et al*. 2008). McLane *et al*. (2011a) found that provenances throughout the range can be expected to lose productivity during summer under predicted warmer conditions, but they will gain productivity in cooler seasons, potentially balancing those losses. McLane *et al.* found that provenances near the centre of the range would perform best under future climates. O'Neill *et al*. (2008) found that different populations of *Pinus contorta* are likely to respond very differently to climate change

Short-term provenance trials have been initiated more recently to explore patterns of variation and adaptation to climatic conditions for *Pinus contorta*, and for *Picea glauca*, *P. engelmannii*, and their hybrids (Liepe *et al.* 2016). Fifteen to 20% of the total variance among populations could be directly linked to climate variables expressed as complex multi-trait adaptations to different ecological regions. However, the authors found that adaptation to climate does not always correspond linearly to temperature gradients. They identified a relatively small number of uniquely adapted populations for each species that could be used to manage assisted gene flow to address climate change.

5.3. Current and emerging technologies for assessing and analysing genetic diversity

A survey of the literature revealed that genetic diversity has been assessed for at least 28 woody species in at least 42 new studies since the 2012 report was published (Table 5.1). The methods range from provenance trials and other quantitative analyses of phenotypic traits (15 articles) to use of ISSR markers (five articles) and one genetic association study. The major difference between studies published prior to *versus* after 2012 was in the use of allozymes to assess genetic diversity in the earlier studies: at least 37 allozyme studies were published before 2012, but none since that date. One exception is a meta-analysis by Roberts and Hamann (2015) of previous allozyme-based studies of 22 western North American tree species, in which they examined current patterns of genetic diversity in relation to glacial refugia. Since 2012, microsatellites have been the most commonly used markers for assessing genetic diversity (17 articles).

Field tests, especially revisiting previously established provenance trials, have regained popularity with the current interest in understanding responses to climate change. At least 17 articles returned from our literature search employed quantitative trait analyses including evaluations of growth, survival, phenology, cold tolerance, nitrogen fixation, wood quality, blister rust impacts and seedling recruitment (Table 5.1).

There has been increased research focus since 2012 on tree species that are not important for commercial forestry. This trend reflects growing interest in planting for restoration and designing conservation strategies in the face of challenges such as climate change.

5.4. Trends in genetic diversity

Most of the recent studies of tree genetics examined effects on genetic diversity in light of one or more of the following factors:

- Forest harvest
- Climate change
- Invasive species
- Habitat fragmentation

Studies have not generally exposed a reduction in genetic diversity as a result of selective tree breeding (see for example, El-Kassaby and Ritland, 1996; Stoehr and El-Kassaby, 1997), although authors recommended continued monitoring to ensure avoidance of unacceptable losses of genetic diversity. A survey of the more recent literature revealed similar results.

Graignic *et al*. (2016) reported weak and possibly transient genetic consequences of selection cutting on sugar maple (*Acer saccharum*). They found that genetic parameters such as number of alleles, and allelic richness were similar between cohorts and between selectively harvested forest and old growth. However, they found evidence of a genetic bottleneck and reduced heterozygosity in the harvested site. Their results indicate that multiple harvests over subsequent rotations may result in erosion of maternal genetic diversity and fixation of deleterious alleles.

Fageria and Rajora (2014) used microsatellite markers to determine whether silvicultural practices affect the genetic diversity and population structure of white spruce (*Picea glauca*) in Saskatchewan. They found no significant effect, but recommended using multiple types of markers to monitor potential impacts. Similarly, Namroud *et al*. (2012) found no significant impact of selection for height growth on genetic diversity of white spruce. They used 1134 SNPs from 709 expressed genes to assess the impact of artificial selection and found that neither the reduction in sample size nor the increase in selection intensity appeared to affect the genetic diversity of selected populations.

Impacts of climate change on genetic diversity are in part due to population fluctuations in response to habitat availability. In Canada, many habitats may expand with warming climates. Russell and Krakowski (2012) examined the potential for adaptation of the cypress tree *Callitropsis nootkatensis* to current and future climates and found that populations are likely to expand, which would likely have no negative impacts on genetic diversity. Joyce and Rehfeldt (2018) found that contemporary habitat for eastern white pine (*Pinus strobus*) is likely to experience sustained deterioration over coming decades, with resulting loss of genetic diversity. Much depends on whether novel genetic variation migrates into newly suitable habitat as climate warming creates appropriate environmental conditions north of the current distribution. Assisted migration is particularly important for species that are limited to high elevations because they may face habitat loss as the climate warms. Vance (2019) discussed the vulnerability of a high-altitude conifer, subalpine larch (*Larix lyallii*), to changing climatic conditions (e.g., increased summer drought). He suggested that the species is unlikely to persist without significant action to conserve genetic diversity via establishment in new habitat.

Invasive species pose a challenge to genetic diversity of some native tree species. The emerald ash borer is rapidly reducing population size or extirpating populations of ash species (*Fraxinus* spp.). Pathogens such as white pine blister rust and butternut canker have had similar but less extreme impacts on populations of *Pinus monticola* (King *et al.,* 2018) and *Juglans cinerea*, respectively (Beardmore *et al*., 2017). Research examining expected resulting losses of genetic diversity in these species is currently lacking.

Habitat fragmentation is commonly associated with other threats to the genetic diversity of forest tree populations, such as climate change. For example, southern Ontario exhibits a high degree of habitat fragmentation and hosts the majority of Canada's threatened and endangered tree species. Budd *et al.* (2015) studied one of these species, the magnolia *Magnolia acuminata*, to determine if genetic diversity can be maintained in fragmented, peripheral populations. They found evidence of sub-structuring among small populations, reflecting low gene flow which is expected to lead to loss of genetic diversity. A study of fragmented populations of eastern white cedar (*Thuja occidentalis,* Xu *et al.*, 2012) did not reveal a sub-structuring trend or differences in genetic diversity, but fragmented populations had significantly higher inbreeding levels than did large continuous populations.

5.5. Methods used for the characterization of forest genetic resources

Characterization of FGR over the past few decades has experienced a revolution in methods. Quantitative studies with provenance and progeny trials have been supplemented with marker-based population genetics using isozymes, RAPDs, and RFLPs, and more recently by genome-wide (e.g., SNP) markers. Most of these methods are still used in various contexts. Table 5.2 presents 67 scientific articles on genetic diversity in trees published since 2012, sorted by species. Almost half of the articles addressed some aspect of adaptation or evolution, and employed association analysis, gene discovery, gene expression, or quantitative analysis of field trials. White spruce (*Picea glauca*) was by far the most studied species, and has emerged as a model species among the Canadian conifers. Studies by research teams from British Columbia and Quebec produced results on *P. glauca* organelle sequencing, gene structure, variation in gene copy number, development of SNP genotyping arrays, association analysis, and gene expression. This effort has advanced our understanding of evolution, defence mechanisms, genetic basis for adaptation to climate, identification of genes involved in wood formation and genome assembly.

Table 5.2. Basic genetic information acquired since 2012 on Canadian tree species by Canadian scientists.

Species	Topic	Publication
Abies balsamea	Phylogeography	Less pollen-mediated gene flow for more signatures of glacial lineages: congruent evidence from balsam fir cpDNA and mtDNA for multiple refugia in eastern and central North America. (Cinget *et al.* 2015a)
Abies balsamea, A. lasiocarpa	Hybrid zone dynamics, mtDNA, cpDNA	Integrating phylogeography and paleoecology to investigate the origin and dynamics of hybrid zones: insights from two widespread North American firs. (Cinget *et al.* 2015b)
Acer rubrum	Gene discovery	Differential levels of gene expression and molecular mechanisms between red maple (*Acer rubrum*) genotypes resistant and susceptible to nickel toxicity

Species	Topic	Publication
		revealed by transcriptome analysis. (Nkongolo *et al.* 2018)
Alnus rubra	Phylogenetics	Characterization of chloroplast genomes of *Alnus rubra* and *Betula cordifolia*, and their use in phylogenetic analyses in Betulaceae. (Lee *et al.* 2019)
Betula alleghaniensis, B. papyrifera, B. lenta	Phylogenetics	Despite introgressive hybridization, North American birches (*Betula* spp.) maintain strong differentiation at nuclear microsatellite loci. (Thomson *et al.* 2015)
	Phylogeography	A similar phylogeographical structure among sympatric North American birches (*Betula*) is better explained by introgression than by shared biogeographical history. (Thomson *et al.* 2015)
Betula papyrifera	Gene expression	Analysis of gene expression associated with copper toxicity in white birch (*Betula papyrifera*) populations from a mining region. (Djeukam *et al.* 2016)
	Gene regulation	Decrypting the regulation and mechanism of nickel resistance in white birch (*Betula papyrifera*) using cross-species metal-resistance genes. (Theriault *et al.* 2016)
	Transcriptome analysis, gene expression, function	Comprehensive transcriptome analysis of response to nickel stress in white birch (*Betula papyrifera*). (Theriault *et al.* 2016)
Picea glauca	Organelle sequencing	Organellar genomes of white spruce (*Picea glauca*): assembly and annotation. (Jackman, *et al.* 2016)
	Evolution and gene structure	Evolution of gene structure in the conifer *Picea glauca*: a comparative analysis of the impact of intron size. (Sena *et al.* 2014.)
	Evolution, adaptation	Differential introgression reveals candidate genes for selection across a spruce (*Picea sitchensis* × *P. glauca*) hybrid zone (Hamilton *et al.* 2013)
	Copy number variants, evolution of standing genetic diversity	Spontaneous mutations and transmission distortions of genic copy number variants shape the standing genetic variation in *Picea glauca*. (Sahli *et al.* 2017)
	Evolution, introgression	Genetic architecture and genomic patterns of gene flow between hybridizing species of *Picea*. (De La Torre *et al.* 2015)
	Evolution, introgression	Genome-wide admixture and ecological niche modelling reveal the maintenance of species boundaries despite long history of interspecific gene flow. (De La Torre *et al.* 2014)

Species	Topic	Publication
	Evolution, introgression	Adaptation and exogenous selection in a *Picea glauca* × *Picea engelmannii* hybrid zone: implications for forest management under climate change. (De La Torre *et al*. 2014)
	SNP genotyping arrays generated for breeding and population genetic studies	Development of high-density SNP genotyping arrays for white spruce (*Picea glauca*) and transferability to subtropical and nordic congeners. (Pavy *et al*. 2013)
	Generality of SNP markers, white spruce as a model species	The landscape of nucleotide polymorphism among 13,500 genes of the conifer *Picea glauca*, relationships with functions, and comparison with *Medicago truncatula*. (Pavy *et al*. 2013)
	Transcriptome analysis, gene discovery; defense mechanisms	Cell-type-and tissue-specific transcriptomes of the white spruce (*Picea glauca*) bark unmask fine-scale spatial patterns of constitutive and induced conifer defense. (Celedon *et al*. 2017)
	Association mapping and co-expression networks; complex wood traits	Genetic architecture of wood properties based on association analysis and co-expression networks in white spruce (Lamara *et al*. 2016)
	Gene mapping	A high-resolution reference genetic map positioning 8.8 K genes for the conifer white spruce: Structural genomics implications and correspondence with physical distance. (Pavy *et al*. 2017)
	Genetic basis for adaptation to climate; SNPs	Genetic adaptation to climate in white spruce involves small to moderate allele frequency shifts in functionally diverse genes. (Hornoy *et al*. 2015)
	Genetic control of resistance to spruce budworm	Insect herbivory (*Choristoneura fumiferana*, Tortricidea) underlies tree population structure (*Picea glauca*, Pinaceae). (Parent *et al*. 2017)
	Local adaptation to climate	Fine-scale geographic variation in photosynthetic-related traits of *Picea glauca* seedlings indicates local adaptation to climate. (Benomar *et al*. 2015)
	Genetic variation in drought adaptation	Adaptive genetic variation to drought in a widely distributed conifer suggests a potential for increasing forest resilience in a drying climate. (Depardieu *et al*. 2020)
	Genetic variation in gene expression of adaptive traits	Are long-lived trees poised for evolutionary change? Single locus effects in the evolution of gene expression networks in spruce. (Verta *et al*. 2013)

Species	Topic	Publication
	Identifying and characterising genes involved in wood formation	Modular organization of the white spruce (*Picea glauca*) transcriptome reveals functional organization and evolutionary signatures. (Raheriso, *et al.* 2015)
	Variation in gene expression	The Genetic Landscape of Transcriptional Networks in a Combined Haploid/Diploid Plant System. (Verta, *et al.* 2014)
	Structure and expression of genes involved in drought tolerance	Expansion of the dehydrin gene family in the Pinaceae is associated with considerable structural diversity and drought-responsive expression. (Stival Sena *et al.* 2018)
	Chloroplast genome sequenced	Complete Chloroplast Genome Sequence of a White Spruce (*Picea glauca*, Genotype WS77111) from Eastern Canada. (Lin, *et al.* 2019)
	Genome assembly	Improved white spruce (*Picea glauca*) genome assemblies and annotation of large gene families of conifer terpenoid and phenolic defense metabolism. (Warren *et al.* 2015.)
	Genome assembly	Assembling the 20 Gb white spruce (*Picea glauca*) genome from whole-genome shotgun sequencing data. (Birol *et al.* 2013)
Picea mariana	Candidate SNPs for association testing	The genomic architecture and association genetics of adaptive characters using a candidate SNP approach in boreal black spruce. (Prunier *et al.* 2013)
	Identifying climate and pollution-related SNPs	Genetic signatures of natural selection in response to air pollution in red spruce (*Picea rubens*, Pinaceae (Bashalkhanov *et al.* 2013)
Picea sitchensis	Selection, migration effect on adaptation to climate change	Divergent selection and heterogeneous migration rates across the range of Sitka spruce (*Picea sitchensis*). (Holliday *et al.* 2012)
	SNP combinations to predict adaptive phenotypes	Predicting adaptive phenotypes from multilocus genotypes in Sitka spruce (*Picea sitchensis*) using random forest. (Holliday *et al.* 2012)
	Discovering genes for adaptive traits	Sequencing of Sitka spruce (*Picea sitchensis*) cDNA libraries constructed from autumn buds and foliage reveals autumn-specific spruce transcripts. (Reid *et al.* 2013)
	Latitudinal clines in cold acclimation	Metabolic dynamics during autumn cold acclimation within and among populations of Sitka spruce (*Picea sitchensis*). (Dauwe *et al.* 2012)
	Demographic history shaping	Long-distance pollen dispersal during recent colonization favors a rapid but partial recovery of

Species	Topic	Publication
	evolutionary trajectory	genetic diversity in *Picea sitchensis*. (Elleouet and Aitken 2019)
	Mitochondrial genome	Largest complete mitochondrial genome of a gymnosperm, Sitka Spruce (*Picea sitchensis*), indicates complex physical structure. (Jackman *et al*. 2019)
Picea glauca, P. sitchensis	spruce transcriptome analysis	Transcriptome profiling in conifers and the PiceaGenExpress database show patterns of diversification within gene families and interspecific conservation in vascular gene expression. (Raherison *et al*. 2012)
Picea glauca, P. mariana, P. glauca x *engelmannii* hybrids	Copy number variations and adaptation	CNVs into the wild: screening the genomes of conifer trees (*Picea* spp.) reveals fewer gene copy number variations in hybrids and links to adaptation. (Prunier *et al*. 2017)
Picea glauca, P. sitchensis	Gene function	The expression pattern of the *Picea glauca* Defensin 1 promoter is maintained in *Arabidopsis thaliana*, indicating the conservation of signalling pathways between angiosperms and gymnosperms. (Germain *et al*. 2012)
Picea glauca, P. sitchensis, P. engelmannii	Introgression and adaptation	Fine-scale environmental variation contributes to introgression in a three-species spruce hybrid complex. (Hamilton, *et al*. 2015)
Picea spp.	Climatic clines	Time to get moving: assisted gene flow of forest trees (Aitken and Bemmels 2016)
Picea mariana, P. rubens	Gene flow bias and association with climate	Asymmetry matters: A genomic assessment of directional biases in gene flow between hybridizing spruces. (de Lafontaine and Bousquet, 2017)
	Heterogeneous patterns of introgression at gene level using SNPs	Tracking the progression of speciation: variable patterns of introgression across the genome provide insights on the species delimitation between progenitor–derivative spruces (*Picea mariana* × *P. rubens*). (de Lafontaine *et al*. 2015)
Picea glauca, P. contorta	De novo transcriptome assembly and RNAseq	Conservation and divergence of gene expression plasticity following c. 140 million years of evolution in lodgepole pine (*Pinus contorta*) and interior spruce (*Picea glauca* × *Picea engelmannii*). (Yeaman *et al*. 2014)
Picea glauca, P. contorta	Association genetics; candidate genes for adaptation	Convergent local adaptation to climate in distantly related conifers. (Yeaman *et al.* 2016)

Species	Topic	Publication
Picea spp., *Pinus* spp.	Sequence capture, resource for diversity and adaptation studies	Exome capture from the spruce and pine giga-genomes. (Suren *et al*. 2016)
Pinus albicaulis	Testing effectiveness of assisted migration	Whitebark pine (*Pinus albicaulis*) assisted migration potential: testing establishment north of the species range. (McLane and Aitken, 2012)
Pinus contorta, P. banksiana	Population structure and introgression using SNPs	Effects of introgression on the genetic population structure of two ecologically and economically important conifer species: lodgepole pine (*Pinus contorta* var. *latifolia*) and jack pine (*Pinus banksiana*). (Cullingham *et al*. 2013)
	Population structure and introgression using SNPs	Characterizing the physical and genetic structure of the lodgepole pine×jack pine hybrid zone: mosaic structure and differential introgression. (Cullingham *et al*. 2012)
	Species and hybrid determinants in hybrid zone, SNPs	Spatial and genetic structure of the lodgepole×jack pine hybrid zone. (Burns, *et al*. 2019)
Pinus flexilis	Gene mapping, rust resistance, association genetics	Limber pine (*Pinus flexilis* James) genetic map constructed by exome-seq provides insight into the evolution of disease resistance and a genomic resource for genomics-based breeding. (Liu *et al*. 2019)
	Gene mapping, rust resistance, association genetics	Genetic mapping of *Pinus flexilis* major gene (Cr4) for resistance to white pine blister rust using transcriptome-based SNP genotyping. (Liu, *et al*. 2016)
Pinus monticola	Association analysis using SNPs, disease resistance, adaptation	Genetic diversity and population structure of whitebark pine (*Pinus albicaulis* Engelm.) in western North America. (Liu *et al*. 2016)
Pinus strobus	Tree rings, adaptation to climate, association genetics	Tree rings provide a new class of phenotypes for genetic associations that foster insights into adaptation of conifers to climate change. (Housset *et al*. 2018)
	Adaptation to climate, SNPs, SSRs, association analysis	Single-locus versus multilocus patterns of local adaptation to climate in eastern white pine (*Pinus strobus*, Pinaceae). (Rajora *et al*. 2016)
Populus trichocarpa	SNP arrays for evolution study	A 34K SNP genotyping array for *Populus trichocarpa*: design, application to the study of natural populations

Species	Topic	Publication
		and transferability to other *Populus* species. (Geraldes *et al*. 2013)
	Landscape genomics	Landscape genomics of *Populus trichocarpa*: the role of hybridization, limited gene flow, and natural selection in shaping patterns of population structure. (Geraldes *et al*. 2014)
	Phylogeny	Whole plastome sequencing reveals deep plastid divergence and cytonuclear discordance between closely related balsam poplars, *Populus balsamifera* and *P. trichocarpa* (Salicaceae). (Huang *et al*. 2014)
Populus angustifolia, P. balsamifera, P. deltoides	Evolution	Plant–herbivore interactions in a trispecific hybrid swarm of *Populus*: assessing support for hypotheses of hybrid bridges, evolutionary novelty and genetic similarity. (Floate *et al.* 2016)
Populus tremuloides, P. balsamifera, P. deltoides	Gene expression	Transcriptome Analysis of Poplar during Leaf Spot Infection with *Sphaerulina* spp. (Foster *et al*. 2015)
Pseudotsuga menziesii	Gene discovery, resistance to root rot	Gene expression profiling of a compatible interaction between Douglas-fir and the root rot fungal pathogen *Phellinus sulphurascens*. (Islam *et al.* 2013)
Salix spp.	Phylogeny	Phylogenetic relationships of American willows (*Salix* L., Salicaceae). (Lauron-Moreau *et al*. 2015)
Sorbus decora, S. americana	Gene expression variation	Phytogeographic and genetic variation in *Sorbus*, a traditional antidiabetic medicine—adaptation in action in both a plant and a discipline. (Bailie *et al*. 2016)

5.6. Needs, challenges and opportunities for increasing the availability of information on forest genetic resources

Needs identified by jurisdictions include development of targeted communications strategies that are specific to FGR subject matter and to the jurisdiction.

More resources are needed, in terms of both funds and expertise. In particular, there is a need for greater leadership and more engagement of personnel at provincial and federal levels to build public awareness of the importance of FGR, as well as policy reflecting FGR.

Challenges for developing information on FGR include: limits on research and travel resources for provincial government staff, reducing opportunities for learning and collaboration across provincial borders; long timelines within government in the approval and production of publications, and; the difficulty in engaging the public on genetic diversity. In Ontario, additional challenges have arisen as a result of the closure of the Ontario Tree Seed Plant and resulting loss of staff with relevant expertise.

Opportunities include building key messages regarding FGR into existing websites, continuing or strengthening FGR management in undergraduate and technical school curricula, the growing interest in restoration and reclamation and recognition of the need for genetically appropri ate seed sources, and capitalizing on social media to communicate about FGR.

5.7. Priorities for capacity-building and research in this area

Priorities for capacity-building and research include strengthening scientific support for management of FGR, and studying patterns of diversity for traits such as drought resistance, pest and disease resistance, and wood properties in selective tree breeding populations.

In Ontario, a priority is rebuilding capacity lost as a result of closure of the Ontario Tree Seed Plant and loss of other programming. The Forest Gene Conservation Association (FGCA) has obtained funds to support applied research and operational programs, including measuring assisted migration field trials to inform seed transfer policies.

In Quebec, there is a need for training of highly qualified personnel and funding for additional human resources. Directing funding to FGR genomic research *per se* instead of only as a by-product of selective tree breeding, is seen as a priority.

Literature Cited

Aitken, S.N. and Bemmels, J.B., 2016. Time to get moving: assisted gene flow of forest trees. Evolutionary Applications, 9(1), pp.271-290.

Albouyeh, R., Farzaneh, N., Bohlmann, J., and Ritland, K. 2010. Multivariate analysis of digital gene expression profiles identifies a xylem signature of the vascular tissue of white spruce (*Picea glauca*). Tree Genetics and Genomics 6: 601–611.

Bailie, A., Renaut, S., Ubalijoro, E., Guerrero-Analco, J.A., Saleem, A., Haddad, P., Arnason, J.T., Johns, T. and Cuerrier, A., 2016. Phytogeographic and genetic variation in *Sorbus*, a traditional antidiabetic medicine—adaptation in action in both a plant and a discipline. PeerJ, 4, p.e2645.

Bashalkhanov, S., Eckert, A.J. and Rajora, O.P., 2013. Genetic signatures of natural selection in response to air pollution in red spruce (*Picea rubens*, Pinaceae). Molecular ecology, 22(23), pp.5877-5889

Beardmore, T., Forbes, K., Toner, M., Williams, M. and Romero-Severson, J., 2017. Butternut health and genetic diversity in New Brunswick, Canada. In In: Sniezko, Richard A.; Man, Gary; Hipkins, Valerie; Woeste, Keith; Gwaze, David; Kliejunas, John T.; McTeague, Brianna A., tech. cords. 2017. Gene conservation of tree species—banking on the future. Proceedings of a workshop. Gen. Tech. Rep. PNW-GTR-963. Portland, OR: US Department of Agriculture, Forest Service, Pacific Northwest Research Station. p. 192. (Vol. 963).

Beaulieu, J., and Simon, J.P. 1994. Genetic structure and variability in *Pinus strobus* in Quebec. Canadian Journal of Forest Research 24: 1726–1733.

Beaulieu, J. and Simon, J.P., 1994. Inheritance and linkage relationships of allozymes in *Pinus strobus* L. Silvae genetica, 43(4), pp.253-261.

Beland, J.D., Krakowski, J., Ritland, C.E., Ritland, K., and El-Kassaby, Y.A. 2005. Genetic structure and mating system of northern *Arbutus menziesii* populations. Canadian Journal of Botany 83: 1581–1589.

Benomar, L., Lamhamedi, M.S., Villeneuve, I., Rainville, A., Beaulieu, J., Bousquet, J. and Margolis, H.A., 2015. Fine-scale geographic variation in photosynthetic-related traits of *Picea glauca* seedlings indicates local adaptation to climate. Tree physiology, 35(8), pp.864-878.

Birol, I., Raymond, A., Jackman, S.D., Pleasance, S., Coope, R., Taylor, G.A., Yuen, M.M.S., Keeling, C.I., Brand, D., Vandervalk, B.P. and Kirk, H., 2013. Assembling the 20 Gb white spruce (*Picea glauca*) genome from whole-genome shotgun sequencing data. Bioinformatics, 29(12), pp.1492-1497.

Bousquet, J., Cheliak, W.M., and Lalonde, M. 1987a. Allozyme variability in natural populations of green alder (*Alnus crispa*) in Quebec. Genome 29: 345–352.

Bousquet, J., Cheliak, W.M., and Lalonde, M. 1987b. Genetic differentiation among 22 mature populations of green alder (*Alnus crispa*) in central Quebec. Canadian Journal of Forest Research 17(3): 219–227.

Bousquet, J., Cheliak, W.M., and Lalonde, M. 1987c. Genetic diversity within and among 11 juvenile populations of green alder (*Alnus crispa*) in Canada. Physiologia Plantarum 70: 311–318.

Bousquet, J., Cheliak, W.M., and Lalonde, M. 1988. Allozyme variation within and among mature populations of speckled alder (*Alnus rugosa*) and relationships with green alder (*Alnus crispa*). American Journal of Botany 75(11):1678–1686.

Bower, A.D., and Aitken, S.N. 2007. Mating system and inbreeding depression in whitebark pine (*Pinus albicaulis* Engelm.). Tree Genetics and Genomes 3: 379–388.

Boys, J., Cherry, M., and Dayanandan, S. 2005. Microsatellite analysis reveals genetically distinct populations of red pine (*Pinus resinosa*, Pinaceae). American Journal of Botany 92(5): 833–841.

Budd, C., Zimmer, E. and Freeland, J.R., 2015. Conservation genetics of *Magnolia acuminata*, an endangered species in Canada: Can genetic diversity be maintained in fragmented, peripheral populations? Conservation genetics, 16(6), pp.1359-1373.

Burns, I., James, P.M., Coltman, D.W. and Cullingham, C.I., 2019. Spatial and genetic structure of the lodgepole × jack pine hybrid zone. Canadian Journal of Forest Research, 49(7), pp.844-853.

Celedon, J.M., Yuen, M.M., Chiang, A., Henderson, H., Reid, K.E. and Bohlmann, J., 2017. Cell-type-and tissue-specific transcriptomes of the white spruce (*Picea glauca*) bark unmask fine-scale spatial patterns of constitutive and induced conifer defense. The Plant Journal, 92(4), pp.710-726.

Chhatre, V.E. and Rajora, O.P., 2014. Genetic divergence and signatures of natural selection in marginal populations of a keystone, long-lived conifer, eastern white pine (*Pinus strobus*) from northern Ontario. PloS one, 9(5).

Chen, C., Liewlaksaneeyanawin, C., Funda, T., Kenawy, A., Newton, C.H., and El-Kassaby, Y.A. 2008. Development and characterization of microsatellite loci in western larch (Larix occidentalis Nutt.). Molecular Ecology Resources 9: 843–845.

Cinget, B., Gérardi, S., Beaulieu, J. and Bousquet, J., 2015a. Less pollen-mediated gene flow for more signatures of glacial lineages: congruent evidence from balsam fir cpDNA and mtDNA for multiple refugia in eastern and central North America. PloS one, 10(4).

Cinget, B., de Lafontaine, G., Gérardi, S. and Bousquet, J., 2015b. Integrating phylogeography and paleoecology to investigate the origin and dynamics of hybrid zones: insights from two widespread North American firs. Molecular Ecology, 24(11), pp.2856-2870.

Cullingham, C.I., Cooke, J.E. and Coltman, D.W., 2013. Effects of introgression on the genetic population structure of two ecologically and economically important conifer species: lodgepole pine (*Pinus contorta* var. *latifolia*) and jack pine (*Pinus banksiana*). Genome, 56(10), pp.577-585.

Cullingham, C.I., James, P.M., Cooke, J.E. and Coltman, D.W., 2012. Characterizing the physical and genetic structure of the lodgepole pine × jack pine hybrid zone: mosaic structure and differential introgression. Evolutionary applications, 5(8), pp.879-891.

Dancik, B.P., and Yeh, F.C. 1983. Allozyme variability and evolution of lodgepole pine *Pinus contorta* var. *latifolia* and jack pine *Pinus banksiana* in Alberta Canada. Canadian Journal of Genetics and Cytology 25(1): 57– 64.

Dauwe, R., Holliday, J.A., Aitken, S.N. and Mansfield, S.D., 2012. Metabolic dynamics during autumn cold acclimation within and among populations of Sitka spruce (*Picea sitchensis*). New Phytologist, 194(1), pp.192-205.

de Lafontaine, G. and Bousquet, J., 2017. Asymmetry matters: A genomic assessment of directional biases in gene flow between hybridizing spruces. Ecology and evolution, 7(11), pp.3883-3893 de Lafontaine, G., Prunier, J., Gérardi, S., and Bousquet, J., 2015. Tracking the progression of speciation: variable patterns of introgression across the genome provide insights on the species delimitation between progenitor–derivative spruces (*Picea mariana* × *P. rubens*). Molecular ecology 24, no. 20: 5229-5247.

De La Torre, A., Ingvarsson, P.K. and Aitken, S.N., 2015. Genetic architecture and genomic patterns of gene flow between hybridizing species of *Picea*. Heredity, 115(2), pp.153-164.

De La Torre, A.R., Roberts, D.R. and Aitken, S.N., 2014. Genome-wide admixture and ecological niche modelling reveal the maintenance of species boundaries despite long history of interspecific gene flow. Molecular ecology, 23(8), pp.2046-2059.

De La Torre, A.R., Wang, T., Jaquish, B. and Aitken, S.N., 2014. Adaptation and exogenous selection in a *Picea glauca* × *Picea engelmannii* hybrid zone: implications for forest management under climate change. New Phytologist, 201(2), pp.687-699.

Depardieu, C., Girardin, M.P., Nadeau, S., Lenz, P., Bousquet, J. and Isabel, N., 2020. Adaptive genetic variation to drought in a widely distributed conifer suggests a potential for increasing forest resilience in a drying climate. New Phytologist,) 227: 427–439

Dhar, A., Balliet, N. and Hawkins, C.D., 2014. Variability in height growth, survival and nursery carryover effect of Betula papyrifera provenances. Scandinavian Journal of Forest Research, 29(2), pp.132-143.

Djeukam, C.L., Theriault, G., Michael, P. and Nkongolo, K.K., 2016. Analysis of gene expression associated with copper toxicity in white birch (*Betula papyrifera*) populations from a mining region. Biotechnology Journal International, pp.1-10.

Donini, P., Liu, J.-J., and Ekramoddoullah, A.K.M. 2009. Identification and characterization of the WRKY transcription factor family in Pinus monticola. Genome 52(1): 77–88.

Echt, C.S., Deverno, L.L., Anzidei, M., and Vendramin, G.G. 1998. Chloroplast microsatellites reveal population genetic diversity in red pine, *Pinus resinosa* Ait. Molecular Ecology 7:307–316.

El-Kassaby, Y.A. and Ritland, K., 1996. Impact of selection and breeding on the genetic diversity in Douglas-fir. Biodiversity & Conservation, 5(6), pp.795-813.

Elleouet, J.S. and Aitken, S.N., 2019. Long-distance pollen dispersal during recent colonization favors a rapid but partial recovery of genetic diversity in *Picea sitchensis*. New Phytologist, 222(2), pp.1088-1100.

Evans, L.M., Kaluthota, S., Pearce, D.W., Allan, G.J., Floate, K., Rood, S.B. and Whitham, T.G., 2016. Bud phenology and growth are subject to divergent selection across a latitudinal gradient in Populus angustifolia and impact adaptation across the distributional range and associated arthropods. Ecology and evolution, 6(13), pp.4565-4581.

Fageria, M.S., Rajora, O.P. 2014. Effects of silvicultural practices on genetic diversity and population structure of white spruce in Saskatchewan. Tree Genetics & Genomes 10, 287–296.

Fageria, M.S. and Rajora, O.P., 2013. Effects of harvesting of increasing intensities on genetic diversity and population structure of white spruce. Evolutionary applications, 6(5), pp.778-794.

Farmer, R.E., Cheliak, W.M., Perry, D.J., Knowles, P., Barrett, J., and Pitel, J. 1988. Isozyme variation in balsam poplar along a latitudinal transect in northwestern Ontario. Canadian Journal of Forest Research 18: 1078–1081.

Floate, K.D., Godbout, J., Lau, M.K., Isabel, N. and Whitham, T.G., 2016. Plant–herbivore interactions in a trispecific hybrid swarm of *Populus*: assessing support for hypotheses of hybrid bridges, evolutionary novelty and genetic similarity. New Phytologist, 209(2), pp.832-844.

Foster, A.J., Pelletier, G., Tanguay, P. and Seguin, A., 2015. Transcriptome analysis of poplar during leaf spot infection with *Sphaerulina* spp. PLoS One, 10(9).

Fowler, D.P., and Morris, R.W. 1977. Genetic diversity in red pine: evidence for low genetic heterozygosity. Canadian Journal of Forest Research, 7:343–347.

Gapare, W.J., Yanchuk, A.D., and Aitken, S.N. 2007. Optimal sampling strategies for capture of genetic diversity differ between core and peripheral populations of *Picea sitchensis* (Bong.) Carr. Conservation Genetics 9(2): 411–418.

Geraldes, A., Difazio, S.P., Slavov, G.T., Ranjan, P., Muchero, W., Hannemann, J., Gunter, L.E., Wymore, A.M., Grassa, C.J., Farzaneh, N. and Porth, I., 2013. A 34K SNP genotyping array for *Populus trichocarpa*: design, application to the study of natural populations and transferability to other *Populus* species. Molecular Ecology Resources, 13(2), pp.306-323.

Geraldes, A., Farzaneh, N., Grassa, C.J., McKown, A.D., Guy, R.D., Mansfield, S.D., Douglas, C.J. and Cronk, Q.C., 2014. Landscape genomics of Populus trichocarpa: the role of hybridization, limited gene flow, and natural selection in shaping patterns of population structure. Evolution, 68(11), pp.3260-3280.

Germain, H., Lachance, D., Pelletier, G., Fossdal, C.G., Solheim, H. and Séguin, A., 2012. The expression pattern of the *Picea glauca* Defensin 1 promoter is maintained in *Arabidopsis thaliana*, indicating the conservation of signalling pathways between angiosperms and gymnosperms. Journal of experimental botany, 63(2), pp.785-795.

Godbout, J., Beaulieu, J., and Bousquet, J. 2010. Phylogeographic structure of jack pine (*Pinus banksiana*; Pinaceae) supports the existence of a coastal glacial refugium in northeastern North America. American Journal of Botany 97(11): 1903–1912.

Godbout, J., Fazekas, A., Newton, C.H., Yeh, F.C., and Bousquet, J. 2008. Glacial vicariance in the Pacific Northwest: evidence from a lodgepole pine mitochondrial DNA minisatellite for multiple genetically distinct and widely separated refugia. Molecular Ecology 17(10): 2463–2475.

Godbout, J., Gros-Louis, M.C., Lamothe, M. and Isabel, N., 2020. Going with the flow: Intraspecific variation may act as a natural ally to counterbalance the impacts of global change for the riparian species *Populus deltoides*. Evolutionary Applications, 13(1), pp.176-194.

Graignic, N., Tremblay, F. and Bergeron, Y., 2013. Development of polymorphic nuclear microsatellite markers in sugar maple (*Acer saccharum* Marsh.) using cross-species transfer and SSR-enriched shotgun pyrosequencing. Conservation Genetics Resources, 5(3), pp.845-848.

Graignic, N., Tremblay, F. and Bergeron, Y., 2014. Geographical variation in reproductive capacity of sugar maple (*Acer saccharum* Marshall) northern peripheral populations. Journal of Biogeography, 41(1), pp.145-157.

Graignic, N., Tremblay, F. and Bergeron, Y., 2016. Genetic consequences of selection cutting on sugar maple (*Acer saccharum* Marshall). Evolutionary applications, 9(6), pp.777-790.

Graignic, N., Tremblay, F. and Bergeron, Y., 2018. Influence of northern limit range on genetic diversity and structure in a widespread North American tree, sugar maple (*Acer saccharum* Marshall). Ecology and evolution, 8(5), pp.2766-2780.

Haitao, L., Wang, X., and Hamann, A. 2010. Genetic adaptation of aspen (*Populus tremuloides*) populations to spring risk environments: a novel remote sensing approach. Canadian Journal of Forest Research 40 (11): 2082–2090.

Hamilton, J.A. and Aitken, S.N., 2013. Genetic and morphological structure of a spruce hybrid (*Picea sitchensis* × *P. glauca*) zone along a climatic gradient. American Journal of Botany, 100(8), pp.1651-1662.

Hamilton, J.A., De la Torre, A.R. and Aitken, S.N., 2015. Fine-scale environmental variation contributes to introgression in a three-species spruce hybrid complex. Tree genetics & genomes, 11(1), p.817.

Hamilton, J.A., Lexer, C. and Aitken, S.N., 2013. Differential introgression reveals candidate genes for selection across a spruce (*Picea sitchensis* × *P. glauca*) hybrid zone. New Phytologist, 197(3), pp.927-938.

Hawley, G.J., and Hayes, D.H. 1994. Genetic diversity and population structure of red spruce (*Picea rubens*). Canadian Journal of Botany 72: 1778–1786.

Holliday, J.A., Ritland, K., and Aitken, S.N. 2010. Widespread ecologically-relevant genetic markers developed from association mapping of climate-related traits in Sitka spruce (*Picea sitchensis*). The New Phytologist 188: 501–514.

Holliday, J.A., Suren, H. and Aitken, S.N., 2012. Divergent selection and heterogeneous migration rates across the range of Sitka spruce (*Picea sitchensis*). Proceedings of the Royal Society B: Biological Sciences, 279(1734), pp.1675-1683.

Holliday, J.A., Wang, T. and Aitken, S., 2012. Predicting adaptive phenotypes from multilocus genotypes in Sitka spruce (*Picea sitchensis*) using random forest. G3: Genes, Genomes, Genetics, 2(9), pp.1085-1093.

Hornoy, B., Pavy, N., Gerardi, S., Beaulieu, J. and Bousquet, J., 2015. Genetic adaptation to climate in white spruce involves small to moderate allele frequency shifts in functionally diverse genes. Genome biology and evolution, 7(12), pp.3269-3285.

Housset, J.M., Nadeau, S., Isabel, N., Depardieu, C., Duchesne, I., Lenz, P. and Girardin, M.P., 2018. Tree rings provide a new class of phenotypes for genetic associations that foster insights into adaptation of conifers to climate change. New Phytologist, 218(2), pp.630-645.

Huang, D.I., Hefer, C.A., Kolosova, N., Douglas, C.J. and Cronk, Q.C., 2014. Whole plastome sequencing reveals deep plastid divergence and cytonuclear discordance between closely related balsam poplars, *Populus balsamifera* and *P. trichocarpa* (Salicaceae). New Phytologist, 204(3), pp.693-703.

Islam, M.A., Sturrock, R.N. and Ekramoddoullah, A.K., 2013. Gene expression profiling of a compatible interaction between Douglas-fir and the root rot fungal pathogen *Phellinus sulphurascens*. Phytopathology, 103(6), pp.583-593.

Jackman, S.D., Coombe, L., Warren, R.L., Kirk, H., Trinh, E., McLeod, T., Pleasance, S., Pandoh, P., Zhao, Y., Coope, R.J. and Bousquet, J., 2019. Largest Complete Mitochondrial Genome of a Gymnosperm, Sitka Spruce (*Picea sitchensis*), Indicates Complex Physical Structure. bioRxiv, p.601104.

Jackman, S.D., Warren, R.L., Gibb, E.A., Vandervalk, B.P., Mohamadi, H., Chu, J., Raymond, A., Pleasance, S., Coope, R., Wildung, M.R. and Ritland, C.E., 2016. Organellar genomes of white spruce (*Picea glauca*): assembly and annotation. Genome biology and evolution, 8(1), pp.29-41.

Jaquish, B., and El-Kassaby, Y.A. 1998. Genetic variation of western larch in British Columbia and its conservation. Journal of Heredity 89:248–253.

Jorgensen, S.M., and Hamrick, J.L. 1997. Biogeography and population genetics of whitebark pine, *Pinus albicaulis*. Canadian Journal of Forest Research 27:1574–1585.

Joyce, D.G. and Rehfeldt, G.E., 2013. Climatic niche, ecological genetics, and impact of climate change on eastern white pine (*Pinus strobus* L.): Guidelines for land managers. Forest Ecology and Management, 295, pp.173-192.

Kalubi, K.N., Mehes-Smith, M., Narendrula, R., Michael, P. and Omri, A., 2015. Molecular analysis of red maple (*Acer rubrum*) populations from a reclaimed mining region in Northern Ontario (Canada): soil metal accumulation and translocation in plants. Ecotoxicology, 24(3), pp.636-647.

Kanaga, M.K., Ryel, J.R., Mock, K.E., and Pfrender, M.E. 2008. Quantitative-genetic variation in morphological and physiological traits within a quaking aspen (*Populus tremuloides*) population. Canadian Journal of Forest Research 38: 1690–1694.

Kang, B.-Y., Mann, I.K., Major, J.E., and Rajora, O.P. 2010. Near-saturated and complete genetic linkage map of black spruce (*Picea mariana*). BMC Genomics 11:515.

King, J.N., DeBell, J., Kegley, A., Sniezko, R.A., McDonald, G. and Ukrainetz, N., 2018. Provenance variation in western white pine (*Pinus monticola*): the impact of white pine blister rust. In In: Schoettle, Anna W.; Sniezko, Richard A.; Kliejunas, John T., eds. Proceedings of the IUFRO joint conference: Genetics of five-needle pines, rusts of forest trees, and Strobusphere; 2014 June 15-20; Fort Collins, CO. Proc. RMRS-P-76. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. p. 63-80. (Vol. 76, pp. 63-80).

Kitamura, K., and Kawan, S. 2001. Regional differentiation in genetic components for the American beech, *Fagus grandifolia* Ehrh., in relation to geological history and mode of reproduction. Journal of Plant Research 114(3):353–368.

Klápště, J., Lstibůrek, M. and El-Kassaby, Y.A., 2014. Estimates of genetic parameters and breeding values from western larch open-pollinated families using marker-based relationship. Tree genetics & genomes, 10(2), pp.241-249.

Knowles, P. 1984. Genetic variability among and within closely spaced populations of lodgepole pine. Canadian Journal of Genetics and Cytology 26: 177–184.

Krakowski, J., Aitken, S.N., and El-Kassaby, Y. 2003. Inbreeding and conservation genetics in whitebark pine. Conservation Genetics 4: 581–593.

Lamara, M., Raherison, E., Lenz, P., Beaulieu, J., Bousquet, J. and MacKay, J., 2016. Genetic architecture of wood properties based on association analysis and co-expression networks in white spruce. New Phytologist, 210(1), pp.240-255.

Lamarque, L.J., Lortie, C.J., Porté, A.J. and Delzon, S., 2015. Genetic differentiation and phenotypic plasticity in life-history traits between native and introduced populations of invasive maple trees. Biological Invasions, 17(4), pp.1109-1122.

Lamy, S., Bouchard, A., and Simon, J.-P. 1999. Genetic structure, variability and mating system in eastern white cedar (*Thuja occidentalis*) populations of recent origin in an agricultural landscape in southern Quebec. Canadian Journal of Forest Research 29: 1383–1392.

Latutrie, M., Mérian, P., Picq, S., Bergeron, Y. and Tremblay, F., 2015. The effects of genetic diversity, climate and defoliation events on trembling aspen growth performance across Canada. Tree genetics & genomes, 11(5), p.96.

Lauron-Moreau, A., Pitre, F.E., Argus, G.W., Labrecque, M. and Brouillet, L., 2015. Phylogenetic relationships of American willows (*Salix* L., Salicaceae). PLoS One, 10(4).

Lauron-Moreau, A., Pitre, F.E., Brouillet, L. and Labrecque, M., 2013. Microsatellite markers of willow species and characterization of 11 polymorphic microsatellites for *Salix eriocephala* (Salicaceae), a potential native species for biomass production in Canada. Plants, 2(2), pp.203-210.

Lee, S.I., Nkongolo, K., Park, D., Choi, I.Y., Choi, A.Y. and Kim, N.S., 2019. Characterization of chloroplast genomes of *Alnus rubra* and *Betula cordifolia*, and their use in phylogenetic analyses in Betulaceae. Genes & genomics, 41(3), pp.305-316.

Li, W., Kershaw Jr, J.A., Costanza, K.K. and Taylor, A.R., 2020. Evaluating the potential of red spruce (Picea rubens Sarg.) to persist under climate change using historic provenance trials in eastern Canada. Forest Ecology and Management, 466, p.118139.

Liepe, K.J., Hamann, A., Smets, P., Fitzpatrick, C.R. and Aitken, S.N., 2016. Adaptation of lodgepole pine and interior spruce to climate: implications for reforestation in a warming world. Evolutionary applications, 9(2), pp.409-419.

Lin, D., Coombe, L., Jackman, S.D., Gagalova, K.K., Warren, R.L., Hammond, S.A., Kirk, H., Pandoh, P., Zhao, Y., Moore, R.A. and Mungall, A.J., 2019. Complete Chloroplast Genome Sequence of a White Spruce (*Picea glauca*, Genotype WS77111) from Eastern Canada. Microbiology resource announcements, 8(23), pp.e00381-19.

Liu, J.J., Chan, D., Sturrock, R. and Sniezko, R.A., 2014. Genetic variation and population differentiation of the endochitinase gene family in *Pinus monticola*. Plant systematics and evolution, 300(6), pp.1313-1322.

Liu, Z., and Knowles, P. 1991. Patterns of allozyme variation in tamarack (*Larix laricina*) from northern Ontario. Canadian Journal of Botany 69: 2469–2474.

Liu, J.J., Schoettle, A.W., Sniezko, R.A., Sturrock, R.N., Zamany, A., Williams, H., Ha, A., Chan, D., Danchok, B., Savin, D.P. and Kegley, A., 2016. Genetic mapping of Pinus flexilis major gene (Cr4) for resistance to white pine blister rust using transcriptome-based SNP genotyping. BMC genomics, 17(1), p.753.

Liu, J.J., Schoettle, A.W., Sniezko, R.A., Yao, F., Zamany, A., Williams, H. and Rancourt, B., 2019. Limber pine (*Pinus flexilis* James) genetic map constructed by exome-seq provides insight into the evolution of disease resistance and a genomic resource for genomics-based breeding. The Plant Journal, 98(4), pp.745-758.

Liu, J.J., Sniezko, R., Murray, M., Wang, N., Chen, H., Zamany, A., Sturrock, R.N., Savin, D. and Kegley, A., 2016. Genetic diversity and population structure of whitebark pine (*Pinus albicaulis* Engelm.) in western North America. PloS One, 11(12).

Lo, E.Y.Y., Stefanovic, S., Ritland, K., and Dickinson, T.A. 2010 Fine-scale comparisons of genetic variability in seed families of asexually and sexually reproducing *Crataegus* (Hawthorn; Rosaceae). American Journal of Botany 97:1014–1024.

Lu, P., Parker, W.H., Cherry, M., Colombo, S., Parker, W.C., Man, R. and Roubal, N., 2014. Survival and growth patterns of white spruce (Picea glauca [M oench] Voss) rangewide provenances and their implications for climate change adaptation. Ecology and Evolution, 4(12), pp.2360-2374.Makela, M., Michael, P., Theriault, G. and Nkongolo, K.K., 2016. High genetic variation among closely related red oak (*Quercus rubra*) populations in an ecosystem under metal stress: analysis of gene regulation. Genes & Genomics, 38(10), pp.967-976.

Matthes-Sears, U., Stewart, S.C., and Larson,D.W. 1991. Sources of Allozymic variation in *Thuja occidentalis* in Southern Ontario Canada. Silvae Genetica 40: 100–105.

McKown, A.D., Guy, R.D., Klápště, J., Geraldes, A., Friedmann, M., Cronk, Q.C., El-Kassaby, Y.A., Mansfield, S.D. and Douglas, C.J., 2014. Geographical and environmental gradients shape phenotypic trait variation and genetic structure in *Populus trichocarpa*. New Phytologist, 201(4), pp.1263-1276.

McLane, S.C. and Aitken, S.N., 2012. Whitebark pine (*Pinus albicaulis*) assisted migration potential: testing establishment north of the species range. Ecological Applications, 22(1), pp.142-153.

McLane, S.C., Daniels, L.D. and Aitken, S.N., 2011b. Climate impacts on lodgepole pine (*Pinus contorta*) radial growth in a provenance experiment. Forest Ecology and Management, 262(2), pp.115-123.

McLane, S.C., LeMay, V.M. and Aitken, S.N., 2011a. Modeling lodgepole pine radial growth relative to climate and genetics using universal growth-trend response functions. Ecological Applications, 21(3), pp.776-788.

Meirmans, P., Lamothe, M., Périnet, P., and Isabel, N. 2007. Species-specific single nucleotide polymorphism markers for detecting hybridization and introgression in poplar. Canadian Journal of Botany 85: 1082– 1091.

Mimura, M., and Aitken, S.N. 2010. Local adaptation at the range peripheries of Sitka spruce. Journal of Evolutionary Biology 23: 249–258.

Morin, R., Beaulieu, J., Deslauriers, M., Daoust, G., and Bousquet, J. 2000. Low genetic diversity at allozyme loci in *Juglans cinerea*. Canadian Journal of Botany 78: 1238–1243.

Mosseler, A., Rajora, O.P., Major, J.E., and Kim, K.H. 2004. Reproductive and genetic characteristics of rare, disjunct pitch pine populations at the northern limits of its range in Canada. Conservation Genetics 5: 571–583.

Mosseler, A., Egger, K.N., and Hughes, G.A. 1992. Low levels of genetic diversity in red pine confirmed by random amplified polymorphic DNA markers. Canadian Journal of Forest Research 22: 1332–1337.

Mosseler, A.D., Innes, J., and Roberts, B.A. 1991 Lack of allozymic variation in disjunct Newfoundland populations of red pine (*Pinus resinosa*). Canadian Journal of Forest Research 21: 525–528.

Mosseler, A., Major, J.E. and Labrecque, M., 2014. Genetic by environment interactions of two North American *Salix* species assessed for coppice yield and components of growth on three sites of varying quality. Trees, 28(5), pp.1401-1411.

Mosseler, A., Major, J.E. and Ostaff, D., 2017. Distribution of genetic variation in five coppice growth traits among natural populations of seven North American willow (*Salix*) species. Canadian Journal of Forest Research, 47(1), pp.36-46.

Nadeau, S., Godbout, J., Lamothe, M., Gros-Louis, M.C., Isabel, N. and Ritland, K., 2015. Contrasting patterns of genetic diversity across the ranges of *Pinus monticola* and *P. strobus*: A comparison between eastern and western North American postglacial colonization histories. American Journal of Botany, 102(8), pp.1342-1355.

Namroud, M.C., Bousquet, J., Doerksen, T. and Beaulieu, J., 2012. Scanning SNPs from a large set of expressed genes to assess the impact of artificial selection on the undomesticated genetic diversity of white spruce. Evolutionary applications, 5(6), pp.641-656.

Narendrula, R., Spiers, G. and Beckett, P., 2014. Heavy metal analysis in red oak (*Quercus rubra*) populations from a mining region in northern Ontario (Canada): effect of soil liming and analysis of genetic variation. American Journal of Environmental Sciences, 10(4), pp.363-373.

Nkongolo, K., Theriault, G. and Michael, P., 2018. Differential levels of gene expression and molecular mechanisms between red maple (*Acer rubrum*) genotypes resistant and susceptible to nickel toxicity revealed by transcriptome analysis. Ecology and evolution, 8(10), pp.4876-4890.

O'Connell, L.M., Mosseler, A., and Rajora, O.P. 2007. Extensive long-distance pollen dispersal in a fragmented landscape maintains genetic diversity in white spruce. Journal of Heredity 98(7): 640–645.

O'Connell, L., Ritland, K., and Thompson, S.L. 2008. Post-glacial colonization of western redcedar (*Thuja plicata*, Cupressaceae) revealed by microsatellite markers. Botany 86: 194–203.

Oke, O.A. and Wang, J.R., 2013. Assessing effects of seed source and transfer potential of white birch populations using transfer functions. Open Journal of Ecology, 3(05), p.359.

O'Neill, G.A., Hamann, A. and Wang, T., 2008. Accounting for population variation improves estimates of the impact of climate change on species' growth and distribution. Journal of Applied Ecology, 45(4), pp.1040-1049.

Pandey, M. and Rajora, O.P., 2012. Genetic diversity and differentiation of core vs. peripheral populations of eastern white cedar, *Thuja occidentalis* (Cupressaceae). American Journal of Botany, 99(4), pp.690-699.

Parent, G.J., Giguère, I., Germanos, G., Lamara, M., Bauce, É. and MacKay, J.J., 2017. Insect herbivory (*Choristoneura fumiferana*, Tortricidea) underlies tree population structure (*Picea glauca*, Pinaceae). Scientific reports, 7, p.42273.

Pelgas, B., Bousquet, J., Meirmans, P.G., Ritland, K., and Isabel, N. 2011. QTL mapping in white spruce: gene maps and genomic regions underlying adaptive traits across pedigrees, years and environments. BMC Genomics 12: 145–149.

Pavy, N., Deschênes, A., Blais, S., Lavigne, P., Beaulieu, J., Isabel, N., Mackay, J. and Bousquet, J., 2013. The landscape of nucleotide polymorphism among 13,500 genes of the conifer Picea glauca, relationships with functions, and comparison with Medicago truncatula. Genome biology and evolution, 5(10), pp.1910-1925.

Pavy, N., Gagnon, F., Rigault, P., Blais, S., Deschênes, A., Boyle, B., Pelgas, B., Deslauriers, M., Clément, S., Lavigne, P. and Lamothe, M., 2013. Development of high-density SNP genotyping arrays for white spruce (Picea glauca) and transferability to subtropical and nordic congeners. Molecular Ecology Resources, 13(2), pp.324-336.

Pavy, N., Lamothe, M., Pelgas, B., Gagnon, F., Birol, I., Bohlmann, J., Mackay, J., Isabel, N. and Bousquet, J., 2017. A high-resolution reference genetic map positioning 8.8 K genes for the conifer white spruce: Structural genomics implications and correspondence with physical distance. The Plant Journal, 90(1), pp.189-203.

Pavy, N., Pelgas, B., Beauseigle, S., Blais, S., Gagnon, F., Gosselin, I., Lamothe, M., Isabel, N., and Bousquet, J. 2008. Enhancing genetic mapping of complex genomes through the design of highly-multiplexed SNP arrays: application to the large and unsequenced genomes of white spruce and black spruce. BMC Genomics 9: 21.

Perry, D J, and Knowles, P. 1989. Allozyme variation in sugar maple at the northern limit of its range in Ontario, Canada. Canadian Journal of Forest Research 19: 509–514.

Perry, D.J., Knowles, P., and Yeh, F.C. 1990. Allozyme variation of *Thuja occidentalis* L. in northwestern Ontario. Biochemical Systematics and Ecology 18: 111–115.

Piot, A., Prunier, J., Isabel, N., Klápště, J., El-Kassaby, Y.A., Aguilar, J.C.V. and Porth, I., 2019. Genomic diversity evaluation of *Populus trichocarpa* germplasm for rare variant genetic association studies. Frontiers in Genetics, 10.

Porter, R.B., Lacourse, T., Hawkins, B.J. and Yanchuk, A., 2013. Adaptive variation in growth, phenology, cold tolerance and nitrogen fixation of red alder (*Alnus rubra* Bong.). Forest ecology and management, 291, pp.357-366.

Prunier, J., Caron, S. and MacKay, J., 2017. CNVs into the wild: screening the genomes of conifer trees (*Picea* spp.) reveals fewer gene copy number variations in hybrids and links to adaptation. BMC genomics, 18(1), p.97.

Prunier, J., Pelgas, B., Gagnon, F., Desponts, M., Isabel, N., Beaulieu, J. and Bousquet, J., 2013. The genomic architecture and association genetics of adaptive characters using a candidate SNP approach in boreal black spruce. BMC genomics, 14(1), p.368.

Raherison, E.S., Giguère, I., Caron, S., Lamara, M. and MacKay, J.J., 2015. Modular organization of the white spruce (*Picea glauca*) transcriptome reveals functional organization and evolutionary signatures. New Phytologist, 207(1), pp.172-187.

Raherison, E., Rigault, P., Caron, S., Poulin, P.L., Boyle, B., Verta, J.P., Giguère, I., Bomal, C., Bohlmann, J. and MacKay, J., 2012. Transcriptome profiling in conifers and the PiceaGenExpress database show patterns of diversification within gene families and interspecific conservation in vascular gene expression. BMC genomics, 13(1), p.434.

Rajora, O.P., DeVerno, L.L., Mosseler, A., and Innes, D.J. 1998. Genetic diversity and population structure of disjunct Newfoundland and central Ontario populations of eastern white pine (*Pinus strobus*). Canadian Journal of Botany 76: 500–508.

Rajora, O.P., Eckert, A.J. and Zinck, J.W., 2016. Single-locus versus multilocus patterns of local adaptation to climate in eastern white pine (*Pinus strobus*, Pinaceae). PloS one, 11(7).

Rajora, O.P., Mosseler, A. and Major, J.E., 2000. Indicators of population viability in red spruce, Picea rubens. II. Genetic diversity, population structure, and mating behavior. Canadian Journal of Botany, 78(7), pp.941-956.

Ramya, N. and Kabwe, N., 2012. Genetic variation in *Picea mariana* × *P. rubens* hybrid populations assessed with ISSR and RAPD markers. American Journal of Plant Sciences, Vol. 3 No. 6, pp. 731-737.

Reid, K.E., Holliday, J.A., Yuen, M., Nguyen, A., Aitken, S.N. and Bohlmann, J., 2013. Sequencing of Sitka spruce (*Picea sitchensis*) cDNA libraries constructed from autumn buds and foliage reveals autumn-specific spruce transcripts. Tree genetics & genomes, 9(3), pp.683-691.

Ritland, K., Meagher, L.D., Edwards, D.G.W., and El-Kassaby, Y.A. 2005. Isozyme variation and the conservation genetics of Garry oak. Canadian Journal of Botany 83: 1478–1487.

Roberts, D.R., Hamann A. 2015. Glacial refugia and modern genetic diversity of 22 western North American tree species. Proc. R. Soc. B 282: 20142903. http://dx.doi.org/10.1098/rspb.2014.2903

Ross-Davis, A., Ostry, M., and Woeste, K.E. 2008. Genetic diversity of butternut (*Juglans cinerea*) and implications for conservation. Canadian Journal of Forest Research 38 (4): 899–907.

Russell, J.H. and Krakowski, J., 2012. Geographic variation and adaptation to current and future climates of *Callitropsis nootkatensis* populations. Canadian journal of forest research, 42(12), pp.2118-2129.

Sahli, A., Giguere, I., Bousquet, J. and MacKay, J., 2017. Spontaneous mutations and transmission distortions of genic copy number variants shape the standing genetic variation in *Picea glauca*. bioRxiv, p.103796.

Savva, Y., Bergeron, Y., Denneler, B., Koubaa, A., and Tremblay, F. 2008. Effect of interannual climate variations on radial growth of jack pine provenances in Petawawa, Ontario. Canadian Journal of Forest Research 38(3): 619–630.

Semerikov, V.L., and Lascoux, M. 1999. Genetic relationship among Eurasian and American *Larix* species based on allozymes. Heredity 83: 62–70.

Sena, J.S., Giguère, I., Boyle, B., Rigault, P., Birol, I., Zuccolo, A., Ritland, K., Ritland, C., Bohlmann, J., Jones, S. and Bousquet, J., 2014. Evolution of gene structure in the conifer *Picea glauca*: a comparative analysis of the impact of intron size. BMC plant biology, 14(1), p.95.

Stival Sena, J., Giguère, I., Rigault, P., Bousquet, J. and Mackay, J., 2018. Expansion of the dehydrin gene family in the Pinaceae is associated with considerable structural diversity and drought-responsive expression. Tree physiology, 38(3), pp.442-456.

Shunmugam, A.S., Soolanayakanahally, R.Y. and Guy, R.D., 2016. Geo-climatic gradient shapes functional trait variations in *Salix eriocephala* Michx. BioRxiv, p.057745.

Simon, J.P., Bergeron, Y., and Gagnon, D. 1986. Isozyme uniformity in populations of red pine (*Pinus resinosa*) in the Atibiti Region, Quebec. Canadian Journal of Forest Research 16: 1133–1135.

Stoehr, M.U. and El-Kassaby, Y.A., 1997. Levels of genetic diversity at different stages of the domestication cycle of interior spruce in British Columbia. Theoretical and Applied Genetics, 94(1), pp.83-90.

Suarez-Gonzalez, A. and Good, S.V., 2014. Pollen limitation and reduced reproductive success are associated with local genetic effects in *Prunus virginiana*, a widely distributed self-incompatible shrub. Annals of botany, 113(4), pp.595-605.

Suren, H., Hodgins, K.A., Yeaman, S., Nurkowski, K.A., Smets, P., Rieseberg, L.H., Aitken, S. N. and Holliday, J.A., 2016. Exome capture from the spruce and pine giga-genomes. Molecular ecology resources, 16(5), pp.1136-1146.

Talbot, P., Thompson, S.L., Schroeder, W., and Isabel, N. 2011. An efficient single nucleotide polymorphism assay to diagnose the genomic identity of poplar species and hybrids on the Canadian prairies. 2011. Canadian Journal of Forest Research 41: 1102–1111.

Theriault, G., Michael, P. and Nkongolo, K., 2016a. Decrypting the regulation and mechanism of nickel resistance in white birch (*Betula papyrifera*) using cross-species metal-resistance genes. Genes & Genomics, 38(4), pp.341-350.

Theriault, G., Michael, P. and Nkongolo, K., 2016b. Comprehensive transcriptome analysis of response to nickel stress in white birch (*Betula papyrifera*). PloS one, 11(4).

Theriault, G., Nkongolo, K.K. and Michael, P., 2014. Genetic and metal analyses of fragmented populations of *Betula papyrifera* (Marsh) in a mining reclaimed region: identification of population–diagnostic molecular marker. Ecology and evolution, 4(17), pp.3435-3443.

Theriault, G., Nkongolo, K.K., Narendrula, R. and Beckett, P., 2013. Molecular and ecological characterisation of plant populations from limed and metal-contaminated sites in Northern Ontario (Canada): ISSR analysis of white birch (*Betula papyrifera*) populations. Chemistry and Ecology, 29(7), pp.573-585.

Thomson, A.M., Dick, C.W. and Dayanandan, S., 2015b. A similar phylogeographical structure among sympatric North American birches (*Betula*) is better explained by introgression than by shared biogeographical history. Journal of Biogeography, 42(2), pp.339-350.

Thomson, A.M., Dick, C.W., Pascoini, A.L. and Dayanandan, S., 2015a. Despite introgressive hybridization, North American birches (*Betula* spp.) maintain strong differentiation at nuclear microsatellite loci. Tree genetics & genomes, 11(5), p.101.

Thomson, A.M., and Parker, W.H. 2008. Boreal forest provenance tests used to predict optimal growth and response to climate change. 1. Jack pine. Canadian Journal of Forest Research 38(1): 157–170.

Ukrainetz, N.K., Kang, K.-Y., Aitken, S.N., Stoehr, M., and Mansfield, S.D. 2008. Heritability, phenotypic and genetic correlations of coastal Douglas-fir (*Pseudotsuga menziesii*) wood quality traits. Canadian Journal of Forest Research 38: 1536–1546.

Vance, M., 2019. Population genomics of a timberline conifer, subalpine larch (Larix lyallii Parl.) (Doctoral dissertation) University of Victoria, British Columbia.

Verta, J.P., Landry, C.R. and MacKay, J.J., 2013. Are long-lived trees poised for evolutionary change? Single locus effects in the evolution of gene expression networks in spruce. Molecular ecology, 22(9), pp.2369-2379.

Verta, J.P., Landry, C.R. and MacKay, J.J., 2014. The Genetic Landscape of Transcriptional Networks in a Combined Haploid/Diploid Plant System. bioRxiv, p.007153.

Viktora, M., Savidge, R.A., and Rajora, O.P. 2011. Clonal and nonclonal genetic structure of subarctic black spruce (Picea mariana) populations in Yukon territory. Botany 89(2): 133–140.

Walter, R.B., and Emerson, K. 2005. Geographic pattern of genetic variation in *Pinus resinosa*: contact zone between descendants of glacial refugia. American Journal of Botany 92: 92–100.

Warren, R.L., Keeling, C.I., Yuen, M.M.S., Raymond, A., Taylor, G.A., Vandervalk, B.P., Mohamadi, H., Paulino, D., Chiu, R., Jackman, S.D., Robertson, G., Yang, C. , Boyle, B. , Hoffmann, M., Weigel, D., Nelson, D.R., Ritland, C., Isabel, N., Jaquish, B., Yanchuk, A., Bousquet, J., Jones, S.J.M., MacKay, J., Birol, I., and Bohlmann, J., 2015. Improved white spruce (*Picea glauca*) genome assemblies and annotation of large gene families of conifer terpenoid and phenolic defense metabolism. The Plant Journal, 83(2), pp.189-212.

Wyman, J., Bruneau, A., and Tremblay, F.M. 2003. Microsatellite analysis of genetic diversity in four populations of *Populus tremuloides* in Quebec. Canadian Journal of Botany 81(4): 360–367.

Xie, C.Y., Carlson, M.R. and Ying, C.C., 2012. Ecotypic mode of regional differentiation of black cottonwood (Populus trichocarpa) due to restricted gene migration: further evidence from a field test on the northern coast of British Columbia. Canadian journal of forest research, 42(2), pp.400-405.

Xie, C.-Y., Ying, C.C., Yanchuk, A.D., and Holowachuk, D.L. 2009. Ecotypic mode of regional differentiation caused by restricted gene migration: a case in black cottonwood (*Populus trichocarpa*) along the Pacific Northwest coast. Canadian Journal of Forest Research 39(3): 519–525.

Xu, H., Tremblay, F., Bergeron, Y., Paul, V. and Chen, C., 2012. Genetic consequences of fragmentation in “arbor vitae,” eastern white cedar (*Thuja occidentalis* L.), toward the northern limit of its distribution range. Ecology and Evolution, 2(10), pp.2506-2520.

Yang, J., Pedlar, J.H., McKenney, D.W. and Weersink, A., 2015. The development of universal response functions to facilitate climate-smart regeneration of black spruce and white pine in Ontario, Canada. Forest Ecology and Management, 339, pp.34-43.

Yeaman, S., Hodgins, K.A., Lotterhos, K.E., Suren, H., Nadeau, S., Degner, J.C., Nurkowski, K.A., Smets, P., Wang, T., Gray, L.K. and Liepe, K.J., 2016. Convergent local adaptation to climate in distantly related conifers. Science, 353(6306), pp.1431-1433.

Yeaman, S., Hodgins, K.A., Suren, H., Nurkowski, K.A., Rieseberg, L.H., Holliday, J.A. and Aitken, S.N., 2014. Conservation and divergence of gene expression plasticity following c. 140 million years of evolution in lodgepole pine (*Pinus contorta*) and interior spruce (*Picea glauca* × *Picea engelmannii*). New Phytologist, 203(2), pp.578-591.

Yeh, F.C. 1988. Isozyme variation of *Thuja plicata* (Cupressaceae) in British Columbia. Biochemical Systematics and Ecology 16: 373–377.

Yeh, F.C., Chong, D.K.X., and Yang, R.C. 1995. RAPD variation within and among natural populations of trembling aspen (*Populus tremuloides* Michx.) from Alberta. Journal of Heredity 86: 454–460.

Yeh, F.C., and Lavton, C. 1979. The organization of genetic variability in central and marginal populations of lodgepole pine *Pinus contorta* spp. *latifolia*. Canadian Journal of Genetics and Cytology 21:487–503.

Yeh, F.C., DM O'Malley. 1980. Enzyme variations in natural populations of Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, from British Columbia. 1. Genetic variation patterns in coastal populations. Silvae Genetica 29: 83–92.

Ying, L., and Morgenstern, E.K. 1991. The population structure of *Larix laricina* in New Brunswick, Canada. Silvae Genetica 40: 180–184.

Young, A.G., Warwick, S.I. and Merriam, H.G. 1993. Genetic variation and structure at three spatial scales for *Acer saccharum* (sugar maple) in Canada and the implications for conservation. Canadian Journal of Forest Research 23: 2568–2578.

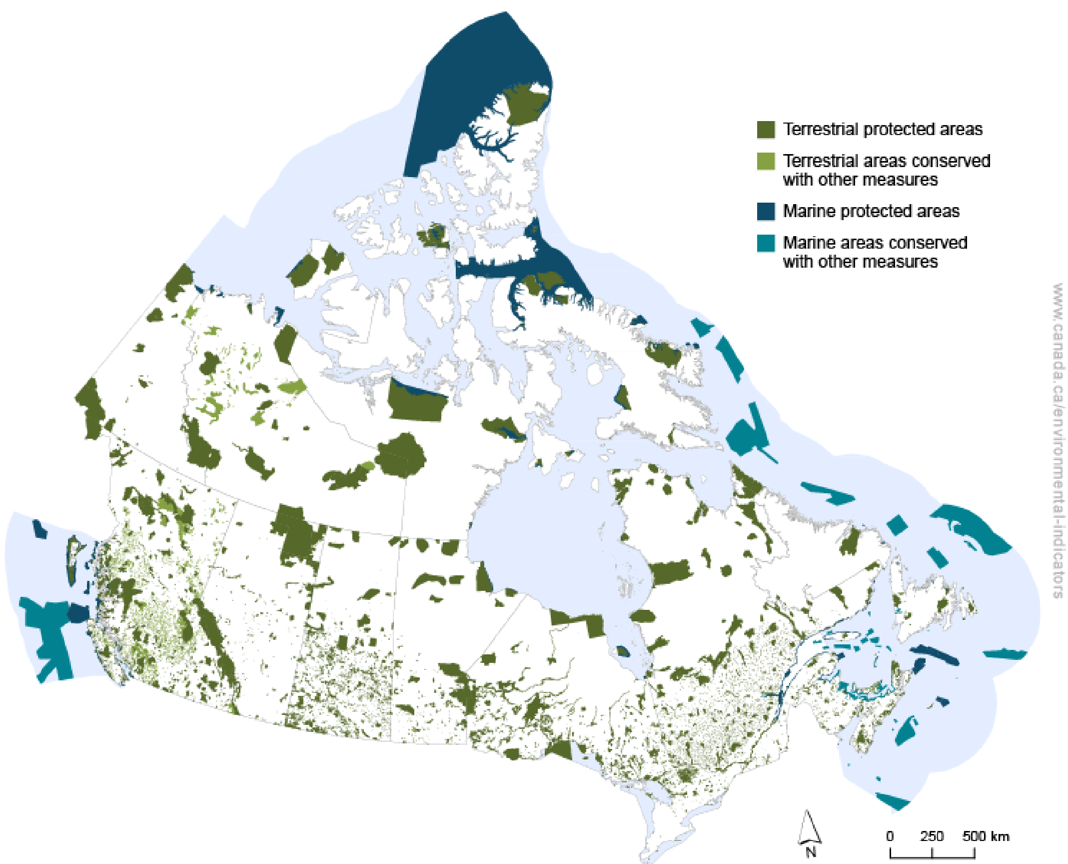
Zinck, J.W. and Rajora, O.P., 2016. Post-glacial phylogeography and evolution of a wide-ranging highly-exploited keystone forest tree, eastern white pine (*Pinus strobus*) in North America: single refugium, multiple routes. BMC Evolutionary Biology, 16(1), p.56.

Chapter 6. *In situ* conservation of forest genetic resources

6.1. Assessment of the state of in situ conservation of forest genetic resources

In Canada, conserved areas include protected areas as well as areas conserved using other means. Areas conserved but not legally "protected" follow the Convention on Biodiversity which defines an "other effective area-based conservation measure" as "a geographically defined area other than a Protected Area, which is governed and managed in ways that achieve positive and sustained long-term outcomes for the *in situ* conservation of biodiversity." Areas that are designated as protected are areas recognized as meeting the international definition for a protected area[2]. Areas conserved with other measures must meet all elements of the Pan-Canadian definition and international definition to be recognized as conserved (Government of Canada, 2019).

Figure 6.1 shows the distribution of protected and other conservation areas in Canada. The largest areas are in the north where population density is relatively low. Some protected and other conserved areas are north of the tree line and many of the largest are in the Boreal Forest where tree species diversity is low.



[2] https://www.iucn.org/theme/protected-areas/about

Figure 6.1. Canada's protected and other conservation areas as of 2019.

Total conserved area of Canada's terrestrial land reached 12.5% by the end of 2020. In British Columbia 19.5% of its terrestrial area is conserved. The next highest jurisdiction is the Northwest Territories with 15.8% of its territory conserved, followed by Alberta with 15.4% conserved, 12. 9% of Quebec, 12.8% of Nova Scotia, 11.8% of Yukon Territory, 11% of Manitoba, 10.7% of Ontario, 10.1% of Nunavut and 9.8% of Saskatchewan. Newfoundland and Labrador, New Brunswick and Prince Edward Island, have each conserved less than 7% of their terrestrial territory (Government of Canada, 2020).

In 2016, the most recent year for which the statistic has been calculated, 29.5 million ha of forest were found within a variety of protected areas across the country (Natural Resources Canada, 2020), more than double the value from 1990 (13.5 million). The period between 2010 and 2016 saw a 5% increase in protected Canadian forest, a trend that is expected to continue (Natural Resources Canada, 2020). Undoubtedly, additional forest land has been conserved between 2016 and 2019 although data for that period are not yet available. In particular, a recently announced $1.3 billion federal fund aimed at establishing and enhancing protected areas is expected to include forest land, with an emphasis on conserving native plants and animals.

There is no centralised approach for *in situ* conservation of trees in Canada, and *in situ* protection is generally not intended to conserve forest genetic resources (FGR) *per se*. The approach to land and freshwater conservation in Canada includes four priorities (Anon, 2018):

1) expand the systems of federal, provincial and territorial protected and conserved areas;
2) promote greater recognition and support for existing Indigenous rights, responsibilities, and priorities in conservation;
3) maximize conservation outcomes; and
4) build support and participation for conservation with a broader community.

A series of corresponding actions are proposed, designed to address the following three key challenges (Anon, 2018):

1) protecting the right amount of habitat to support viable populations of all species;
2) protecting the right areas so protected and conserved areas can function as a representative ecological network, not simply as "islands of green;" and
3) managing areas in a way that seeks cooperation across jurisdictional boundaries, and respects natural boundaries where possible.

Thus, the aim for conserved areas is to protect a range of ecosystems, and populations of forest trees are expected to be protected adequately if forest ecosystems are to be well represented. This has been tested in British Columbia (Chourmouzis *et al.*, 2009) and in Alberta (Krakowski, 2017). In both cases, genetic resources of most native trees are adequately protected at present, but vulnerabilities are exposed when climate change impacts are modeled.

Table 6.1 lists many of the types of conservation areas across the country by jurisdiction. The list is unchanged since the publication of Canada's 2012 FGR report. Two Federal bodies, Parks Canada and Environment and Climate Change Canada, are responsible for 29% and 10% of Canada's terrestrial conserved areas, respectively. The other 61% of conserved land is under provincial or territorial jurisdiction.

Table 6.1. Examples of federal, provincial, territorial, non-governmental, and industry *in situ* conservation areas (from Canada's 2012 FGR report).

Governance	*In situ* (forested) conservation categories	Types of *in situ* conservation categories and description
A) Federal *in situ* conservation areas		
Environment Canada – Canadian Wildlife Service (Federal)	• Migratory Bird Sanctuaries	• Migratory Bird Sanctuaries: any area on private or Crown land that meets one of four criteria: (1) supports bird populations that are concentrated for any part of the year to meet feeding and/or breeding needs, (2) is vulnerable to area-specific threats, (3) supports populations that occupy habitats or restricted geographical areas that are vulnerable to human disturbance, or (4) regularly supports at least 1% of a population of a species or subspecies.[1] These can be forested areas.
	• National Wildlife Areas	• National Wildlife Areas: relatively undisturbed land containing nationally significant aquatic and/or terrestrial ecosystems necessary for plant and animal habitat. These areas are created for conservation as well as scientific and wildlife research purposes.[2]
Aboriginal Peoples (Federal)	• Wildlife Sanctuaries, Protected areas	• Wildlife Sanctuaries can include land set aside as a protected area at the request of Aboriginal Peoples during land-claim negotiations with the Government of Canada. For example, the Ddhaw Ghro, (formerly McArthur Wildlife Sanctuary), was set aside as a habitat protection area at the request of the Northern Tutchone First Nations in the Yukon during land-claim negotiations in the Selkirk First Nations Final Agreement.[3]
Parks Canada (Federal)	• National Parks	• National Parks are established to protect examples of natural landscapes and natural phenomena. National parks

		protect the habitats, wildlife, and ecosystem diversity representative of natural regions.[4]
	• National Park Reserves	• National Park Reserves are set aside as national parks, pending settlement of any outstanding aboriginal land claims. During this interim period, the National Parks Act applies, while allowing traditional hunting, fishing, and trapping activities by Aboriginal peoples. Local Aboriginal people may be involved in reserve anagement.[5]

B) Jurisdictional *in situ* conservation areas

British Columbia Parks	• Ecological Reserves	• Ecological Reserves are established for: conservation of representative examples of British Columbia's ecosystems; protection of rare and endangered plants and animals in their natural habitat; conservation of unique, rare, or outstanding botanical, zoological, or geological phenomena; perpetuation of important genetic resources; and scientific research and educational uses associated with the natural environment.[6]
	• Conservation Lands	• Conservation Lands are areas to conserve and manage critical habitat for the benefit of regionally, nationally, and internationally significant fish and wildlife species. Principal objectives include conserving or managing habitat for: sensitive, vulnerable, or at-risk species; critical species' life-cycle phases such as spawning, rearing, nesting, or winter feeding; important species migration routes or other movement corridors; areas of very high species productivity or diversity. Conservation lands often concurrently provide for a range of wildlife-related opportunities for the public, such as day hiking, hunting and fishing, wildlife viewing, scientific research, and interpretive programs.[7]
	• Wildlife Management Areas	• Wildlife Management Areas require a special level of protection and management. Reasons include: an area's wildlife/habitat values are of regional, provincial, or national significance; special management zones or objectives for wildlife, fish, and their habitats have been identified in a local or regional strategic land-use plan; there is a need to conserve or manage important species and habitats while allowing certain types of activities or developments; a standard "protected area" designation is

		not an available option or is considered too restrictive; a buffer zone or link for a core protected area is desirable.[8]
	• Parks	• Parks are selected for a broad range of activities and uses, many pertaining to recreational activities.[9]
Alberta Tourism, Parks and Recreation	• Ecological Reserves	• Ecological Reserves are conserved for ecological purposes and are representative of natural ecosystems in Alberta that contain rare or endangered native plants or animals or areas with unique examples of natural biological or physical features.[10]
	• Provincial Parks	• Provincial Parks are designated for the conservation of Alberta's natural heritage. They have multiple purposes, including the conservation and management of flora and fauna; the conservation of specified areas that are of geological, historical, ecological, or other scientific interest; facilitating their use and enjoyment for outdoor recreation, education, and appreciation of Alberta's natural heritage; and ensuring their lasting protection for the benefit of present and future generations. [11]
	• Provincial Recreation Areas	• Provincial Recreation Areas are designated to facilitate their use and enjoyment for outdoor recreation by present and future generations.[10]
	• Natural Areas	• Natural Areas are set aside to protect sensitive or scenic public land or natural features on public land from disturbance; to maintain a natural state for use by the public for conservation, nature appreciation, low-intensity outdoor recreation, education, or for any combination of these purposes.[10]
	• Heritage Rangelands	• Heritage Rangelands contain natural landscapes, features, and ecological processes associated with Alberta's rangelands and are designated as such to ensure their conservation and protection using grazing to maintain the grassland ecology.[10]
	• Wilderness Areas	• Wilderness Areas are among the most strictly protected areas in Canada; no developments of any kind are permitted. Travel in wilderness areas is by foot only. Collection, destruction and removal of plant and animal

		material, and other objects of geological, ethnological, historical and scientific interest, are prohibited. Hunting, fishing and the use of horses are not permitted in wilderness areas.[10]
	• Wildland Parks	• Wildland Parks are large, undeveloped natural landscapes. Trails and primitive backcountry campsites may be provided to minimize visitor impacts on natural heritage values. Designated trails for off-highway vehicle are provided in some Wildland parks. Hunting is allowed in some Wildland Parks.[10]
Saskatchewan Tourism, Parks, Culture & Sport	• Ecological Reserves	• Ecological Reserves sustain or are associated with unique or representative parts of the natural environment including water, land, plants, wildlife, and people, with the goal to conserve natural areas to protect genetic resources and to provide areas for scientific research in a natural setting.[12]
	• Game Preserves	• Game Preserves are established for protecting, propagating, managing, controlling, regulating, or enhancing wildlife and its habitat with the goal of conserving and managing a wildlife population and its habitat and can included forested areas.[12]
	• Protected Areas	• Protected Areas offer maximum protection to important, rare, or fragile resources.[12]
	• Natural Environment Parks	• Natural Environment Parks are large natural tracts that protect representative and unique landscapes found in Saskatchewan, with the goal of landscape protection and provision of appropriate recreational opportunities to the public.[12]
	• Wilderness Parks	• Wilderness Parks are large remote areas conserved where low-intensity and non-mechanized wilderness recreation is permitted. A goal is to protect representative areas of Saskatchewan's major ecoregions.[12]
		• Wildlife Development Fund Lands are conserved to improve critical habitat for game and endangered species,

	• Wildlife Development Fund • Land Wildlife Habitat Protection Lands • Wildlife Refuges	aiming to protect or restore wildlife habitat in agricultural and forested areas.[12] • Wildlife Habitat Protection Lands are designated multiple-use provincial Crown lands that provide seasonal or year-round habitat critical to wildlife survival, including rare and endangered species located primarily in the agricultural and forest fringe regions of Saskatchewan.[12] • Wildlife Refuges are designated for the protection, propagation, perpetuation, management, control, regulation, and/or enhancement of wildlife and its habitat and include forested areas.[12]
Manitoba Conservation	• Ecological Reserves	• Ecological Reserves contain rare or sensitive habitats that are set aside as restrictions on uses and activities so that the natural region features endure for future generations.[13]
	• Protected Areas	• Protected Areas prohibit, through legal means, logging, mining (including aggregate extraction), and oil, petroleum, natural gas, or hydro-electric development. Protected areas with this minimum level of protection till remain open for activities such as hunting, trapping, or fishing.[13]
	• Provincial Parks	• Provincial Parks can be, but are not necessarily protected areas; they are classified as: 1. Wilderness Park: preserves that represent areas of a natural region (protected area); 2) Natural Park: accommodate a diversity of recreational uses (maybe protected); 3) Recreation Park: provides recreation opportunities (not protected); 4) Heritage Park: contains resources of cultural or heritage value (may be protected).
	• Public Reserves	• Public Reserves conserve unique and rare natural (biological and geological) features of the province and examples of natural and modified ecosystems. They are set aside for ecosystem and biodiversity conservation, research, education and nature study. [13]
	• Wildlife Management Areas	• Wildlife Management Areas are designated for better management, conservation, and enhancement of the wildlife resource of the province. Hunting and trapping are generally permitted but may be prohibited or restricted in selected areas.[14]

Ontario Parks and Protected Areas	• Provincial Parks	• Provincial Parks are representative of Ontario's ecosystems, biodiversity, and provincially significant natural elements. They provide opportunities for ecologically sustainable outdoor recreation and opportunities for visitors to increase their knowledge and appreciation of Ontario's natural and cultural heritage, and they facilitate scientific research and provide points of reference to support monitoring of ecological change on the broader landscape.[15]
	• Conservation Reserves, Natural Environment Reserves	• Conservation Reserves are similar to Ontario's provincial parks but also provide opportunities for ecologically sustainable land uses, including traditional outdoor heritage activities and associated benefits.[15]
	• Wilderness Areas	• Wilderness Areas are set aside for their conservation in their natural state, aiming to protect flora and fauna.[16]
Faune Québec, Ministère des Ressources naturelles et de la Faune	• National Parks, National Park reserves¸ Wildlife and Biodiversity Preserves, Ecological Reserves as examples	• Protected Areas are dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means. Note, land types that fall under Quebec's Protected Areas include Exceptional Forest Ecosystem, Wildlife Habitat, threatened plant species Habitats, Quebec's National Parks and National Park reserves¸ Wildlife and Biodiversity Preserves, and Ecological Reserves.[17]
New Brunswick Department of Natural Resources	• Protected Natural Areas, Provincial Parks	• Protected Natural Area (PNA) are permanently set-aside for the conservation of biological diversity.[18] PNA Class I requires complete protection as they contain ecologically sensitive features that could be damaged by human activity. All activities are prohibited in these areas, except by permit from the Minister for educational and scientific purposes.[18] PNA Class II ecosystems that are representative of the New Brunswick landscape or that are ecologically important or rare. Certain recreational uses having minimal environmental impact and traditional food-gathering activities are permitted in these areas, but industrial, commercial, and agricultural uses and development are

		prohibited. Educational and scientific activities require a permit.[18]
Nova Scotia Department of the Environment	• Nature Reserves • Wilderness Areas	• Nature Reserves are selected to conserve and protect, in perpetuity, representative and special natural ecosystems, plant and animal species, features and natural processes. Scientific research and education are the primary uses, with recreation being restricted generally.[19] • Wilderness Areas are representative of NS landscapes, native biological diversity, and unique natural features, used for scientific research, education, recreation, and nature-tourism-related activities.[19]
Prince Edward Island Department of the Environment, Energy and Forestry	• Conservation Zones • Wildlife Management Zones • Natural Areas • Provincial Parks	• Conservation Zones are established to conserve animate or inanimate objects of aesthetic, educational, or scientific interest, or for conserving unusual combinations of elements of the natural environment having educational, historical, or scientific interest.[20] • Wildlife Management Area is maintained for the protection, management, and conservation of wildlife and wildlife habitat.[21, 22] • Natural Areas contain natural ecosystems or constitute the habitat of rare, endangered, or uncommon plant or animal species.[21, 22] • Provincial Parks are responsible for maintaining and restoring ecological integrity of the designated area.[21, 22]
Newfound-land & Labrador Department of Environment & Conservation	• Ecological Reserves • Provincial Parks	• Ecological Reserves represent areas smaller than 1000 km^2 designed to protect representative ecosystems or to protect unique, rare, endangered plants, animals, or other elements of Newfoundland and Labrador's natural heritage.[23] • Provincial Parks are established to protect the representative areas of the different ecoregions within the province.[23]

	• Wildlife Reserves • Wilderness Reserves	• Wildlife Reserves are created to protect the habitat of particular wildlife species.[23] • Wilderness Reserves are areas greater than 1000 km^2 designed to protect significant natural features and landscapes and to provide opportunities for low-impact outdoor recreation.[23]
Yukon Department of Environment	• Multiple categories	• Special Management Areas may be parks, habitat protection areas, wildlife areas, or other types.[24] Habitat Protection Areas are identified as requiring special protection under Yukon's *Wildlife Act*.[25]
Northwest Territories Environment and Natural Resources	• Protected Areas • Territorial Parks	• Protected Areas are dedicated to the protection and maintenance of biological diversity and of natural and associated cultural resources and managed through legal or other effective means. • Territorial Parks are divided into the following categories:[26] o Heritage Parks: parks with historical significance. o Natural Environmental Parks: conserve and protect unique, representative, or aesthetically significant natural areas o Recreational Parks: encourage an appreciation for the natural environment or provide recreational activities (including campgrounds). o Wayside Parks: provide for the enjoyment or convenience of the travelling public.

C. Non-governmental organizations *in situ* conservation areas

Ducks Unlimited	• Wetland conservation areas	• DUC Boreal Forest Conservation Program conserves wetland areas in Canada's boreal forest through a combination of ecosystem-based sustainable development that utilizes state-of-the-art best management practices and by promoting the establishment of an extensive network of large, interconnected wetland-rich protected areas.[27] DUC partners with multiple stakeholders, including the federal and jurisdictional governments, industry (e.g., Weyerhaeuser), Aboriginal peoples, academic institutions, foundations, and conservation organizations to help establish a national boreal conservation network of large, wetland-rich protected areas.[28]

Island Nature Trust, Prince Edward Island	• Multiple categories	• The Island Nature Trust is the first private, provincially based Nature Trust in Canada.[29] It is a non-governmental, not-for-profit organization dedicated to the protection and management of Prince Edward Island's Natural Areas. Lands acquired are held in trust and managed for future generations as examples of appropriate and sustained use. Their Trees in Trust program enables donors to pay for a mapped piece of forest, which will then be dedicated in their name.[30,31]
Nature Conservancy of Canada	• Multiple categories	• The Nature Conservancy of Canada (NCC) protects areas of natural diversity for their intrinsic value and for the benefit of our children and those after them.[32] The NCC identifies, plans, and executes the protection of natural spaces and manages and restores them for the long term. This process ensures that our conservation actions (like buying land, removing invasive weeds, or mapping the location of rare species) are efficient and effective.[33] They do so through the following means: o Conservation Agreement: a voluntary, legal agreement between a landowner and conservation organization that permanently limits uses of the land in order to protect its conservation values.[34] o Ecogift Program: Many land and easement donations to the NCC are processed through the federal Ecogift program, which is administered by Environment Canada. The land must be certified by the Minister of the Environment as ecologically sensitive.[35] o Capital donations: Donors receive a tax receipt for the appraised value of the land/conservation agreement.[36] o Donation of Land as Assets: Occasionally, NCC may receive a donation of land of minimal ecological value purely as an asset to be sold, with the proceeds of the sale being invested in projects with higher priority conservation needs.[36]
New Brunswick Nature Trust	• Multiple categories	• Established as New Brunswick's (NB) provincial land trust in 1987, the Nature Trust of NB identifies, promotes, protects, and maintains diverse areas of ecological significance in the province.[37, 38]

Ontario Nature	• Multiple categories	• Ontario Nature protects wild species and wild spaces through conservation, education, and public engagement. Ontario landowners can help conserve the ecological integrity of natural spaces through a number of means, so they are included in Ontario Nature's Nature Reserves System.[39, 40]
D) Forest Industry		
J.D. Irving, Ltd.	• Unique Areas Program	• J.D. Irving, Ltd. (JDI) has been establishing habitat protection areas, including old-growth forests, on its freehold lands since the 1980s. To date, 715 unique areas have been set aside for protection, totaling 77 000 ha.[41] JDI is acting to ensure that areas of ecological importance remain healthy and vibrant through their habitat conservation, green initiatives, stringent policies, environmental education projects, and extensive scientific research.[42]

1. Environment Canada. 2010. 2. Environment Canada. 2010b. 3. Selkirk First Nations 2012. 4. Parks Canada. 2010. 5. Parks Canada. 2009. 6. British Columbia Ministry of Environment. 2010c. 7. British Columbia Ministry of Environment. 2010b. 8. British Columbia a Ministry of Environment. 2010e. 9. British Columbia Parks. 2012. 10. Province of Alberta. 2009. 11. Government of Alberta. 2010. 12. Saskatchewan Tourism, Parks, Culture and Sport. 2010 13. Manitoba Wildlands. 2008. 14. Government of Manitoba. 2010. 15. Ontario Parks. 2009 16. Service Ontario. 2006. 17 Québec Développment durable, Environnement et Parcs. 201. 18. Government of New Brunswick. 2003. 19. Province of Nova Scotia. 2010. 20. Province of Prince Edward Island. 2010c 21. Province of Prince Edward Island. 2010a. 22. Province of Prince Edward Island. 2010b. 23. Newfoundland Department of Environment and Conservation. 2006 24. Environment Yukon. 2010b. 25. Environment Yukon. 2010a. 26. Northwest Territories Environment and Natural Resources. 2010. 27. Ducks Unlimited Canada. 2012a. 28. Ducks Unlimited Canada. 2012b. 29. Island Nature Trust. 2012b. 30. Island Nature Trust. 2007–2009. 31. Island Nature Trust. 2012a. *Donate*. 32. Nature Conservancy of Canada. 2012a. 33. Nature Conservancy of Canada. 2012d. 24. Nature Conservancy of Canada. 2012c. 25. Nature Conservancy of Canada. 2012e. 36. Nature Conservancy of Canada. 2012b. 37.The Nature Trust of New Brunswick. 2012b. 38. The Nature Trust of New Brunswick. 2012a. 39. Ontario Nature 2011a. 40 Ontario Nature. 2011b. 41. J.D. Irving, Limited. 2012b. 42. J.D. Irving, Limited. 2012a.

6.2. Approaches for in situ conservation of forest genetic resources

Gap analyses have been carried out in several jurisdictions to examine adequacy of *in situ* conservation of FGR in protected areas. In British Columbia, most tree species FGR are considered to be adequately protected in most biogeoclimatic units in which they occur (Chourmouzi *et al.*, 2009). A question facing the conservation community with respect to sufficiency of *in situ* conservation is whether the populations that are protected currently are likely to maintain their fitness under predicted future climate scenarios. British Columbia provides an example of detailed examination of that question and, although the work was carried out almost 10 years ago, the results are relevant for *in situ* conservation efforts across the country. Hamann and Aitken (2013) used climate change projections to estimate the adequacy of *in situ* protection of tree genetic resources into the future (Table 6.2). Following assumptions of seed zone delineations to reflect locally adapted habitats as described by Hamann *et al.* (2005), and employing approximately median annual temperature and precipitation projections, Hamann and Aitken assumed that habitat is likely to be suitable at different points in time if the protected areas continue to provide safe reserves with projected climate change. The authors projected availability of habitat under four biological scenarios: no tree migration, no adaptation; migration only; adaptation only, and; both migration and adaptation. The degree of expected migration or adaptation occurring was species specific, and shaped by available genetic variation as well as life history characteristics such as habitat specificity. Where both migration and adaptation were assumed, about 85% of currently protected populations were estimated to be maintained by 2080. Conversely, under the most pessimistic scenario of no migration and no adaptation, the model predicted only 35% of populations would persist to 2080.

Similar gap analyses for the current protection status and under climate change projections have been carried out in Alberta, where Krakowski (2017), who found that protection is adequate in the largest ecoregions (representing 65% of the province's area) but lacking for at least some species in smaller ecoregions.

Table 6.2 Number of protected areas that maintain a sufficient amount of suitable habitat (Area × Expected species frequency ≥10 ha) under four adaptation and migration scenarios (from Hamann and Aitken, 2013).

Species	Current	No Adaptation no migration			Migration only			Adaptation only			Adaptation and Migration		
		2020	2050	2080	2020	2050	2080	2020	2050	2080	2020	2050	2080
Abies amabilis	149	129	113	80	152	136	98	131	117	96	154	143	109
Abies grandis	20	21	21	13	32	51	75	23	26	25	34	55	87
Abies lasiocarpa	295	187	103	65	199	133	83	260	217	171	266	233	181

Species	Current	No Adaptation no migration			Migration only			Adaptation only			Adaptation and Migration		
		2020	2050	2080	2020	2050	2080	2020	2050	2080	2020	2050	2080
Acer circinatum	55	47	51	54	64	75	85	47	51	55	65	76	89
Acer glabrum	102	95	74	73	119	104	101	112	123	126	132	143	149
Acer macrophyllum	55	65	67	64	76	86	93	74	81	95	86	101	125
Alnus tenuifolia	164	86	37	21	115	67	53	153	140	107	175	159	126
Alnus rubra	126	129	127	127	133	137	133	137	146	164	142	157	172
Alnus viridis	253	146	70	32	165	107	76	234	195	145	244	206	159
Arbutus menziesii	2	1	1	1	2	4	5	3	4	5	3	7	11
Betula occidentalis	16	10	7	3	22	28	28	14	17	7	26	38	34
Betula papyrifera	154	127	97	94	140	124	130	180	192	190	191	209	216
Chamaecyparis nootkatensis	111	96	75	40	109	91	55	101	83	53	113	97	63
Cornus nuttallii	14	12	12	11	22	31	33	15	19	25	24	37	46
Corylus cornuta	35	37	28	28	64	63	65	39	39	40	67	70	74
Juniperus scopulorum	15	8	8	2	13	12	10	10	11	5	17	16	16
Larix laricina	33	0	0	0	8	10	9	33	23	6	36	30	17
Larix lyallii	21	4	0	0	6	1	0	4	0	0	7	1	0
Larix occidentalis	39	18	11	0	44	55	53	29	33	26	51	70	66
Malus fusca	39	43	36	30	47	40	39	43	41	39	47	45	48
Picea engelmannii	191	97	76	46	127	104	74	166	165	135	181	177	149
Picea glauca	169	69	13	5	85	35	17	142	101	61	150	111	67
Picea mariana	138	43	7	1	59	30	16	117	90	57	129	100	65
Picea sitchensis	134	125	105	85	129	117	94	128	113	94	134	123	101
Pinus albicaulis	87	40	16	4	61	38	22	50	30	8	67	47	25
Pinus contorta	375	247	162	116	263	201	158	354	311	263	361	331	280

Species	Current	No Adaptation no migration			Migration only			Adaptation only			Adaptation and Migration		
		2020	2050	2080	2020	2050	2080	2020	2050	2080	2020	2050	2080
Pinus monticola	54	52	50	40	75	88	82	58	64	60	80	100	98
Pinus ponderosa	59	46	36	20	60	66	62	77	90	116	89	113	144
Populus balsamifera	212	126	88	82	151	128	125	205	206	218	219	230	250
Populus tremuloides	205	107	53	31	122	78	61	198	185	161	204	193	176
Prunus emarginata	4	5	9	12	10	20	39	5	9	13	10	20	41
Prunus pensylvanica	7	5	2	0	9	4	0	5	2	0	9	4	0
Prunus virginiana	19	9	6	7	16	14	26	17	27	42	24	37	58
Pseudotsuga menziesii	385	342	295	263	379	330	296	412	421	413	450	455	439
Quercus garryana	10	9	9	9	10	10	10	9	9	9	10	10	10
Frangula purshiana	5	6	8	8	13	20	24	6	11	15	13	23	31
Salix bebbiana	72	27	6	8	40	21	20	56	53	44	70	63	56
Salix discolor	7	0	0	0	5	3	1	5	1	0	9	4	1
Salix lucida	43	17	12	12	30	29	28	26	14	20	40	30	35
Salix scouleriana	93	37	11	6	54	37	29	80	76	48	90	88	67
Salix sitchensis	92	65	48	46	87	79	74	80	63	62	102	90	85
Taxus brevifolia	76	72	70	55	93	102	93	74	76	64	96	109	105
Thuja plicata	344	300	277	246	320	297	260	351	346	333	364	363	349
Tsuga heterophylla	345	302	280	241	313	288	253	317	303	285	328	315	296
Tsuga mertensiana	138	110	67	34	122	87	60	115	87	56	128	103	72

Formal in situ forest genetic diversity conservation programs in Canada

Alberta and Ontario

Alberta has a strategy for *in situ* genetic conservation with a stated goal (Alberta Agriculture and Forestry, 2018): "to contain at least 5,000 mature unrelated individuals in each of three sites per natural subregion in the core of the species' distribution and up to three sites in peripheral or outlying parts of the range."

The objectives of Alberta's *in situ* conservation strategy are:

1) Maintain genetic diversity of the wild populations as the raw material for evolution
2) Maintain populations of known exceptional genetic value
3) Provide genetic reference points for genetic diversity and adaptive traits
4) Provide a reservoir of genetic variation for use in scientific study, education and tree improvement.

After evaluation of current locations of tree species with respect to conservation status, candidate genetic conservation reserves will be identified for any species for which there are conservation gaps. Selection of conservation reserves will be carried out with the aim of representing a range of adaptive genotypes. In cases where information on the genetic basis of trait adaptiveness are lacking, stratification of habitats according to biophysical habitat elements will guide reserve location.

No additional areas will be designated for species that are abundant throughout the natural subregion. The government and industrial groups involved in selective tree breeding projects are also responsible for genetic conservation.

Gaps in the *in situ* conservation of species in Alberta's natural subregions were identified as follows (from Alberta Agriculture and Forestry, 2018):

1) species' range maps were overlain with protected areas. For minor species' ranges, expert advice, field records, and/or habitat modelling was necessary as spatial inventory to generate reliable range maps was often limited or inaccurate;
2) adequacy of existing conservation sites was determined, considering size of area, number and security of reserves based on known occurrences, density, disturbance, and other relevant factors, and;
3) gaps were identified in the existing network of formal *in situ* conservation sites.

The following steps are recommended for filling the *in situ* conservation gaps:

1) locate candidate areas, protect multiple species in a single site wherever possible;
2) prioritize candidate sites by first considering land excluded from the harvesting land base such as protected areas, candidate protected areas with Crown land dispositions, existing buffers, inoperable areas, and non-merchantable stands on Crown lands;
3) confirm inventory of the target species in the priority candidate areas by field verification;
4) fill remaining gaps by selecting additional candidate sites from the list above and confirm the presence of the target species by field verification;

5) formalize genetic conservation areas by establishing protected areas or land dispositions for genetic conservation, or by working with other agencies or groups to align land use direction and priorities to secure either voluntary or formal protection of populations;
6) if dispositions cannot be established at all target sites, the genetic conservation status will still be assessed based on demographics and distribution (i.e., if abundant and widespread but not adequately represented within protected areas or conservation dispositions, status may still be considered secure), and;
7) monitor every 10 to 20 years to ascertain if the area is still meeting the objective, if it is still needed, or if it needs to be substituted with another area or more actively managed.

Ontario's Forest Gene Conservation Association (FGCA) operates as an independent forest genetics association in southern Ontario which is home to the highest tree species diversity in Canada (Forest Gene Conservation Association, 2018). The FGCA was established initially under the umbrella of the Ontario Tree Improvement Board, then was part of Forest Genetics Ontario before that program was terminated in 2015. FGCA's vision is "a healthy, productive, sustainable forest across urban and rural southern Ontario that includes the full breadth of natural woody plant genetic diversity and contributes to local ecosystem integrity and the social and economic welfare of current and future generations of Ontarians." Its specific mission is "to broadly promote forest gene conservation and to advise and assist our members and associates to apply genetic resource management principles within their forest conservation and management programs in urban and rural landscapes in southern Ontario." In pursuit of that mission, the FGCA strives to support Crown land sustainable forest license holders, conservation authorities, municipalities, and private landowners with advice and assistance in forest tree genetic conservation.

The FCGA has four goals for 2016-2021 related to genetic conservation (Forest Gene Conservation Association, 2018):

1) Biologically Appropriate Reforestation: Increase the quality and quantity of source-identified, native species' seed.
2) Promotion of Gene Conservation Principles: Increase awareness of FGCA's programs among forest management and conservation sectors.
3) Species Conservation and Restoration: Increase awareness of native species diversity and threats to their status, and develop programs for recovery.
4) Climate Change Adaptation: Increase awareness and use of genetic resource management principles to help conserve and improve existing native forest resilience.

6.3. Organization of in situ conservation of forest genetic resources

There is no coordinated national effort for *in situ* conservation of FGR. Conservation of biological resources is the responsibility of each province or territory and, outside of national parks and several other federal designations (Table 6.1), this includes most forested land.

Consequently, FGR conservation approaches and focus vary among jurisdictions across the country.

Each province and territory has a combination of government and non-government-managed protected areas as described in Table 6.1. FGR conservation efforts are organised differently in each province, and only British Columbia, Alberta and Ontario have strategies for FGR which include *in situ* conservation.

British Columbia

In British Columbia, the Genetic Conservation Technical Advisory Committee (GCTAC) of the Forest Genetics Council (FGC) has the mandate to:

1) provide guidance and recommendations to the FGC on genetic conservation issues for indigenous forest trees, including conservation issues associated with climate change and forest health;
2) lead the development of genetic conservation research, measurement, strategies, and programs;
3) provide business planning direction and recommend project budgets to the FGC for GCTAC funded activities, and;
4) review reports submitted for GCTAC-funded activities.

The Ministry of Forests, Lands, and Natural Resource Operations (FLNRO) Tree Improvement Branch with the University of British Columbia Centre for Forest Conservation Genetics and GCTAC members (Provincial and federal government, university and industry representatives) are responsible for different tasks in the implementation of the 5-year strategic plan.

Alberta

Alberta has plans for *in situ* genetic conservation for more than 30 native tree species. The status and gaps are summarized for each species and region. *In situ* genetic conservation in Alberta is primarily driven by ecogeography where genetic data are lacking, under the assumption that ecotypic distribution is a reasonable surrogate for adaptive trait distribution.

6.4. The main players / stakeholders of in situ conservation

Table 6.1 presents the main groups involved in establishing and managing protected areas. In general, these groups work to represent and maintain natural ecosystems, with less focus at the species level and less still on FGR. Researchers at universities, provincial governments, and Natural Resources Canada play a significant role by advising managers of protected areas in FGR, based on research at the species level.

6.5. Criteria applied for identifying or establishing new in situ units or areas for the conservation of forest genetic resources

In British Columbia and Alberta, candidate sites contain a census population of the target species that is > 5000 individuals. At least three populations per ecological unit is considered to provide adequate redundancy for species representation despite fire or other factors. In British Columbia, for species that do not have large continuous or contiguous populations, decisions regarding reserve size are based on ground-truthing census numbers, obtaining genetic estimates of effective population size and genetic diversity, and geographic patterns of genetic diversity (Genetic Conservation Technical Advisory Committee, 2016). In Alberta, a metapopulation approach is taken for species that do not form large contiguous populations, whereby gene flow is maintained through a landscape matrix and diversity is sustained through migration. When tree populations consist of scattered individuals that include several of known high value (e.g., trees with insect or disease resistance), those individuals are included if possible (Alberta Agriculture and Forestry, 2018). Alberta also stipulates that the reserve should be maintained for at least 50 years so that all of the trees will have an opportunity to contribute to the next generation.

6.6. Needs, challenges and opportunities for improving in situ conservation of forest genetic resources

In British Columbia, *in situ* conservation appears to be generally adequate in present conditions. The protected areas analysis is currently under revision by the Genetic Conservation Technical Advisory Committee, to include new protected areas. The new 'seed planning' zones are based on climate change predictions, so conservation measures will have to be evaluated at least every decade as climate change progresses.

A challenge noted in Alberta, but likely shared in other jurisdictions, is ensuring responsibility and understanding of *in situ* FGR conservation and management by different departments or government agencies. For example, site establishment and subsequent FGR monitoring is costly and is under the responsibility of Environment and Parks departments. Under limited financial resources with little or no compensation to the department or agency responsible for genetic conservation, a common result at present is that FGR conservation is not included in the objectives for protected areas.

Human resources and capacity for FGR management is a challenge throughout all jurisdictions, although less so in British Columbia. Financial resources are needed as well to study and describe genetic resources of less commercially valuable species and for establishing new conservation areas.

6.7. Priorities for capacity-building and research in this area

Stronger scientific support is needed at multiple government levels and across Canada, in order to gain knowledge of FGR directly, rather than as merely a by-product of tree breeding or other research endeavours. Notably, the array of available genetic diversity studies cited in Chapter 5 (e.g., Table 5.1, 5.2) typically do not address range-wide genetic diversity of their focal tree species, and they collectively represent only a subset of Canadian tree species. In addition, independent studies vary in terms of study design, molecular data employed, analytical approaches, degree or criteria of interpretation, and data archiving practices. Still, several of the studies cited above, as well as province-level research and management in several jurisdictions (reviewed in sections 6.2 and 6.3) already exemplify productive approaches regarding FGR stewardship. Increased government engagement at a national scale would foster enhanced collaboration across jurisdictions on this topic. Dedicated funding capacity would be required to facilitate this process.

Literature Cited

Alberta Agriculture and Forestry. 2018. Gene Conservation Plan for Native Tress of Alberta, second edition. Forest Management Branch, Alberta Agriculture and Forestry. Edmonton, Alberta. 112 pp. + viii.

Anon. 2018. One with Nature: A Renewed Approach to Land and Freshwater Conservation in Canada. A Report of Canada's Federal, Provincial and Territorial Departments Responsible for Parks, Protected Areas, Conservation, Wildlife and Biodiversity. 51 p. https://static1.squarespace.com/static/57e007452e69cf9a7af0a033/t/5c9cd18671c10bc304619547/1553781159734/Pathway-Report-Final-EN.pdf

Chourmouzis, C., Yanchuk, A.D., Hamann, A., Smets, P. and Aitken, S.N., 2009. Forest tree genetic conservation status report 1: *In situ* conservation status of all indigenous British Columbia species. Centre for Forest Conservation Genetics. Forest Genetics Council of BC, and BC Min. For. Range, For. Sci. Prog. Victoria, BC Tech. Rep, 53.

Forest Gene Conservation Association. 2018. www.fgca.net

Genetic Conservation Technical Advisory Committee. 2016. Genetic Conservation Technical Advisory Committee (GCTAC) Strategic Plan2015-2020. Forest Genetics Council of British Columbia. Victoria, BC, Canada. 16 pp.

Government of Canada. 2020. https://www.canada.ca/en/environment-climate-change/services/national-wildlife-areas/protected-conserved-areas-database.html

Hamann, A. and Aitken, S.N., 2013. Conservation planning under climate change: accounting for adaptive potential and migration capacity in species distribution models. Diversity and Distributions, 19(3), pp.268-280.

Hamann, A., Smets, P., Yanchuk, A.D. and Aitken, S.N., 2005. An ecogeographic framework for *in situ* conservation of forest trees in British Columbia. Canadian Journal of Forest Research, 35(11), pp.2553-2561.

Krakowski, J., 2017. Forest gene conservation programs in Alberta, Canada. In In: Sniezko, Richard A.; Man, Gary; Hipkins, Valerie; Woeste, Keith; Gwaze, David; Kliejunas, John T.; McTeague, Brianna A., tech. cords. 2017. Gene conservation of tree species—banking on the future. Proceedings of a workshop. Gen. Tech. Rep. PNW-GTR-963. Portland, OR: US Department of Agriculture, Forest Service, Pacific Northwest Research Station: 170-173. (Vol. 963, pp. 170-173).

Natural Resources Canada. 2020. The State of Canada's Forests; Annual Report 2019. Ottawa, ON. 77 p.

Chapter 7. *Ex situ* conservation of forest genetic resources

7.1. State of ex situ conservation.

This chapter describes the current state of *ex situ* conservation of forest genetic resources (FGR) in Canada, as of 2019, and the needs and priorities for improving the program. The information presented *ex situ* is based on a survey completed by experts in the following jurisdictions: Alberta, British Columbia, New Brunswick, Nova Scotia, Ontario and Quebec. In the pan-Canadian survey contributing to the first Canadian report on FGR (Canada FGR, 2012), a species prioritisation effort was made to assess the state of *ex situ* genetic conservation for Canada's 125 tree species. Each assessed a species was given a ranking value (RV) between RV0-RV3, defined as follows:

RV0 – No apparent cause for concern for the species
RV1 – May require *ex situ* conservation but current knowledge is inadequate
RV2 – Requires *ex situ* conservation
RV3 – Requires specific genetic conservation measures to ensure the integrity of the native gene pool

In 2012, 39 tree species (Table 7.1) were categorised as RV3. This chapter contains the updated species-specific information associated with the reassessment of those 39 species.

Table 7.1: Total number of *ex situ* accessions stored at the national or subnational levels for species assessed as RV3.

Species Listed as RV3	Subnational No. of Accessions	National No. of Accessions	Total (Subnational/National) No. of Accessions
Aesculus glabra	13	0	13
Asimina triloba	19	2	21
Betula lenta	22	8	30
Betula occidentalis	187	11	198
Carya glabra var. *odorata*	16	0	16
Carya laciniosa	22	0	22
Castanea dentata	16	0	16
Cornus florida	28	4	32
Cornus nuttallii	96	1	97
Fagus grandifolia	20	1	21
Fraxinus americana	28	793	821
Fraxinus nigra	13	812	825
Fraxinus pennsylvanica	18	677	695
Fraxinus profunda	5	1	6

Species Listed as RV3	**Subnational No. of Accessions**	**National No. of Accessions**	**Total (Subnational/National) No. of Accessions**
Fraxinus quadrangulata	25	37	62
Gleditsia triacanthos	34	1	35
Gymnocladus diocus	56	5	61
Juglans cinerea	140	329	469
Juniperus maritima	51	0	51
Liriodendron tulipifera	33	16	49
Magnolia acuminata	26	16	42
Morus rubra	17	0	17
Nyssa sylvatica	15	2	17
Pinus albicaulis	1423	62	1485
Pinus flexilis	586	108	694
Pinus monticola	161	9	170
Pinus rigida	13	29	42
Pinus strobus	2187	334	2521
Populus deltoides ssp. *monilifera*	3	0	3
Prunus emarginata	151	0	151
Ptelea trifolia	32	11	43
Quercus ellipsoidalis	11	0	11
Quercus garryana	6	0	6
Quercus muehlenbergii	30	0	30
Quercus prinoides	16	0	16
Quercus shumardii	22	0	22
Ulmus americana	130	43	173
Ulmus rubra	10	24	34
Ulmus thomasii	5	0	5
Total	5,686	3,336	9,022
	63%	37%	100%

The *ex situ* accessions in Table 7.1 reflect the summation of both national and subnational data from the National Tree Seed Centre (NTSC). Although some jurisdictions do not have their own *ex situ* accessions, they are becoming involved in conservation of these tree species through collaboration with the NTSC to store germplasm from within their range. Of the 39 species assessed here, most of the species are hardwoods (33), five of the remaining six species are conifers from the genus *Pinus*, and the final species is *Juniperus maritima*. All 39 species are conserved as either seed lots or living *ex situ* accessions.

As accessions, the NTSC has 24 species in storage while the jurisdictions above collectively all listed species in storage. Ontario on its own stores accessions for all but seven species that occur only in western Canada (British Columbia and Alberta). Most accessions are stored as seed lots, but a few species (i.e., *Juglans cinerea*, *Quercus* spp.) that do not persist well under conventional storage conditions (-20°C) are instead conserved as clones or seedlings (maintained either in clone banks or seed orchards). For *Juglans cinerea*, a species with endangered status both federally and provincially in Canada, germplasm is stored both as clones in one jurisdiction (Ontario) and cryogenically (liquid nitrogen at -196°C) as embryogenic axes at the NTSC facility.

7.2 Main national/subnational stakeholders and their approaches for ex situ conservation (FAO guidance doc. questions 7.2 to 7.5).

There are four main *ex situ* conservation reserves for tree species in Canada: three jurisdictional seed banks (British Columbia Ministry of Forests, Lands and Natural Resource Operations, Alberta Ministry of Sustainable Resource Development, Québec Ministère des Forêts, de la Faune et des Parcs) and the Natural Resources Canada National Tree Seed Centre.

Subnational *ex situ* conservation seed bank activities are guided by jurisdictional *ex situ* conservation plans (e.g., *ex situ* conservation plan for FGR in Alberta, 2018). The majority of their efforts revolve around the collection, processing, testing and storage of seed sources from commercial species for reforestation. In several cases, seed lots representing additional species of interest or endangered species (e.g., *Pinus flexilis*, *Pinus albicaulis* in British Columbia and Alberta) are also stored.

At the national level, the NTSC collects, processes, tests and stores seeds of a diversity of Canadian tree and shrubs species in order to support species conservation and research. Currently, the NTSC has over 16,000 seed lots representing more than 120 species of native trees and shrubs, and it aims to ultimately store representative seed samples collected from throughout the natural ranges of all Canadian species from these groups—totaling about 125 tree species and hundreds of shrub species. For most species, seeds are stored at -20°C, while some recalcitrant hardwood species (e.g., oaks, silver maple) seeds are instead kept at 4°C and collected relatively more frequently to maintain viable seed stocks (https://www.nrcan.gc.ca/science-data/research-centres-labs/forestry-research-centres/atlantic-forestry-centre/national-tree-seed-centre/13449, [accessed April 2020]). The NTSC also has a cryogenic facility that allows for the *ex situ* conservation of tree germplasm that cannot be stored effectively in the long term under the above conditions (i.e., *Juglans cinerea*, *Magnolia acuminata*). Finally, the NTSC has recently made exceptional efforts to conserve ash (*Fraxinus* spp.) seed across all jurisdictions in response to the emerald ash borer (*Agrilus planipennis* Fairmaire; Coleoptera: Buprestidae); an invasive pest that has decimated all ash species in Canada and has spread throughout the range of ash species.

Seed banks are not the only *ex situ* reserves of native tree seed in Canada. Other conservation reserves that contribute to the *ex situ* conservation of a species through seed lot storage or through living collections include provincially and municipally managed arboreta, botanical gardens, ecological centres and genetic conservation associations.

Ex situ conservation reserves represent a minor component of most subnational seedbanks, given that the main focus at the jurisdictional level is to store available selectively bred seed (e.g., maximising gains for yield, pest resistance, *etc*.) of commercially important species. Nonetheless, various research institutions (e.g., universities, government agencies, and research facilities, etc.) benefit from currently conserved *ex situ* stocks, using the accessions and associated expertise for research in many fields of interest including: ecological reclamation; climate change; assisted migration; provenance trials; molecular studies; tissue culture; species restoration, and; research on tree seed storage methods. Finally, additional *ex situ* reserves exist for the public and research scholars as a means to provide documented reference collections for species identification.

7.3 Tree germplasm transfer within or outside of Canada (FAO question 7.6).

The tree breeding material maintained by each province is adapted to local ecophysiographic conditions. Even so, transfer of germplasm occurs between some provinces that share bio-geoclimatic zones (Alberta and British Columbia) or for research purposes (New Brunswick, Alberta, British Columbia, NTSC). Some jurisdictions such as BC ministry of Forests, Lands, Natural Resource Operations & Rural Development use germplasm transfer agreements with agencies external to its department and different transfer agreements are used to meet the specifics of the transfer (i.e., research, seed orchard development, material exchange, etc.). Nationally, the NTSC can supply small quantities of seed strictly for research purposes and is uses a seed request form to direct that process. Internationally, Canada is a member of the OECD seed certification scheme and adheres to those international standards for the export of Canadian seed. No national legislation or guidelines currently exist in Canada regarding the transfer of germplasm (The State of the World's Forest Genetic Resources: Country report Canada, 2012), although Access and Benefit Sharing approaches (ABS) that bear directly on this issue are currently being discussed at the international level (Food and Agriculture Organization, United Nations) with respect to forestry, agriculture, and fisheries.

7.4 Needs, challenges and opportunities for improving ex situ conservation of FGR (FAO question 7.7).

Jurisdictions have identified needs, challenges, and opportunities for *ex situ* conservation activities and programs in Canada (not ordered by priority):

1. Increased qualified personnel with forest genetics and forest insect and disease expertise
2. Increased capacity into the research and expertise in seed storage methods

3. Knowledge of the impacts of forest genetics to mitigate the impacts of forest insect and disease, as well as climate change
4. Increased financial support to programs aimed at *ex situ* conservation
5. Increased exchange of information on *ex situ* conservation programs and stocks at all levels of government
6. Increased knowledge of genetic variation, adaptation and resilience
7. Increased capacity for *ex situ* tree germplasm storage (both conventional and unconventional)
8. Increased awareness and *ex situ* conservation of non-commercial tree species
9. Cost-benefit analysis of presence compared to absence of *ex situ* species conservation
10. Development of a national long-term seed and germplasm conservation strategy

7.5 Priorities for capacity building and research in ex situ conservation (FAO question 7.8)

The following issues were identified by jurisdictions:

1. Develop increased capacity for storage of tree germplasm
2. Centralize data storage of tree species requiring *ex situ* conservation via tree seed databases integrated across government levels.
3. Include climate change in predictive modelling
4. Include insect and disease susceptibility and resilience in predictive modelling
5. Prioritize conservation of species listed as endangered or threatened
6. Conserve genetic variation across the range of species that are listed as endangered or threatened
7. Development of storage protocols for orthodox and unorthodox tree seed
8. Incorporate promising new technologies (e.g., genomics, somatic embryogenesis, water activity) into *ex situ* programs
9. Incorporate GAP analysis and prioritization models to identify and optimize sampling methods
10. Increase public understanding of the 'how and why' of *ex situ* conservation
11. Develop plans and strategies for the conservation of tree species
12. Predict and prevent declines in germination capacity over time through research aimed at understand how it is mediated by effects of seed periodicity, quality, longevity and storage.
13. Understand the optimal number or volume of conserved tree seed required for future needs
14. Increase information exchange across conservation centres by developing workshops on seed collection, purity, certification, seed source and chain of custody up to international standards (International Seed Testing Association) and AOSA

7.6 Conclusion

Although efforts to prioritise species has increased in importance since the last Canadian report, there is still a need for up-to-date information due to multiple challenges including climate change, increased pressures on the forest sector, and the appearance and spread of new and introduced insects and diseases in the country. A survey addressing any new concerns for tree species in Canada (not only the tree species requiring *ex situ* conservation) would be beneficial. Many factors including time, resources (e.g., human, financial, infrastructure, equipment, *etc*.) and in some cases knowledge on how best to store germplasm from individual tree species for the long-term would enhance *ex situ* conservation across the country. Species prioritization for *ex situ* conservation is a key exercise to focus the limited resources that are currently available. Today with the cost of genomics decreasing exponentially, population genetic studies could be conducted at least on priority species. This genetic knowledge could guide *ex situ* collections and maximise genetic diversity of species in storage which would be useful for maximizing the conservation of potentially adaptive genetic variation. These efforts need to be paired with other conservation efforts (i.e., *in situ* conservation, threat management, etc.) to ensure the conservation of the ecological function and adaptive capacity of each tree species.

Literature cited

Alberta Agriculture and Forestry. (2018). *Ex situ* conservation plan for forest genetic resources in Alberta. Retrieved from Alberta Agriculture and Forestry website. URL: https://open.alberta.ca/dataset/519e69de-fb95-4c16-8c2c-749684f48824/resource/5da7da2a-c5dd-4ae8-92b0-3599b42395ac/download/exsitu_gcplan_2018-04.pdf

Report on the State of Canada's Forest Genetic Resources. 2012. Beardmore, T.; Forbes, K.; Simpson, J.D.; Williams, M.; Barnhardt, L.; Dunford, L.; Gauthier, V.; Linehan, B.; McAfee, B.; Myers, M.; Rainville, A.; Sharples. R.; Weng, Y.; Woods, J. Food and Agricultural Organisation, United Nations, Rome, Italy.

Chapter 8. The state of use

8.1. How forest genetic resources are used

Forest genetic resources (FGR) are used each time a tree is used for one of many purposes. This chapter addresses the uses in which particular genetic resources are valued. It is widely recognized that selective tree breeding of a host of traits adds value to seedlings that are used in reforestation. Less well known is the importance of genetic variation in successful restoration or effectiveness of carbon sequestration. Genetic resources are used in conservation programmes, particularly when the threat is an insect pest or disease. Major uses of forest tree species requiring active management are listed in Table 8.1.

Table 8.1. Main forest tree species actively managed for productive aims or ecosystem services (most information unchanged since it appeared in Canada's 2012 FGR Report).

Species	Reforestation	Silviculture	Urban	NTFP	Energy	Carbon	Conservation	Restoration /reclamation
Abies amabilis	X	X						
Abies balsamea	X	X	X	X				X
Abies grandis	X	X		X				
Abies lasiocarpa	X	X	X					
Abies procera	X	X	X	X				
Acer marcrophylum	X	X						
Acer rubrum		X	X					X
Acer saccharum	X	X	X	X				
Alnus rubra	X	X						X
Betula alleghaniensis	X	X	X					X
Betula neoalaskana (syn. *B. pendula*)		X						X
Betula papyrifera		X	X					X
Callitropsis nootkatensis	X	X						
Carya cordiformis			X				X	
Carya ovata			X				X	
Celtis occidentalis			X				X	
Fraxinus Americana	X	X	X					
Fraxinus nigra	X		X	X			X	

Species	Reforestation	Silviculture	Urban	NTFP	Energy	Carbon	Conservation	Restoration /reclamation
Fraxinus pennsylvanica			X					
Juglans cinerea			X	X			X	
Larix laricina	X	X	X					X
Larix lyalli							X	X
Larix occidentalis	X	X					X	
Ostrya virginiana			X				X	
Picea abies	X	X	X					
Picea engelmannii	X	X						
Picea glauca	X	X	X	X		X	X	X
Picea mariana	X	X	X			X		X
Picea rubens	X	X	X					
Picea sitchensis	X	X						
Pinus albicaulis							X	X
Pinus banksiana	X	X	X			X		X
Pinus contorta	X	X	X					X
Pinus flexilis			X				X	X
Pinus monticola	X	X						
Pinus ponderosa	X	X	X					
Pinus rigida	X	X	X			X		X
Pinus resinosa	X	X	X			X		X
Pinus strobus	X	X	X	X		X		
Pinus sylvestris			X	X				
Populus balsamifera	X	X	X					X
Populus deltoides	X		X					X
Populus grandidentata		X	X					X
Populus native hybrids	X	X	X		X	X		
Populus non-native hybrids		X						
Populus tremuloides	X	X	X					X
Pseudotsuga menziesii	X	X	X	X				
Quercus alba			X					X

Species	Reforestation	Silviculture	Urban	NTFP	Energy	Carbon	Conservation	Restoration /reclamation
Quercua bicolour			X		X	X		
Quercus garryanna							X	X
Quercus macrocarpa	X		X					X
Quercus rubra	X	X	X				X	X
Salix spp.			X		X			X
Thuja occidentalis	X	X	X	X				
Thuja plicata	X	X	X					
Tilia Americana			X					X
Tsuga Canadensis	X	X	X					
Tsuga heterophylla	X	X						
Ulmus Americana			X				X	X
Ulmus rubra			X					

The main explicit use of tree FGR is in selective tree breeding programmes. The extent to which genetic resources are used can be measured by the number or proportion of seedlings sourced from selected-seed orchards that are planted in reforestation programmes. In British Columbia, 67% of the 300 million seedlings planted on public lands in 2020 were grown from this source. The average genetic gain for volume is greater than 21% (https://forestgeneticsbc.ca/health-productivity/). The proportion of selectively bred seed is lower in other provinces, but overall at least 50% of seed needs for reforestation are met by seed orchards. Most seed requirements are met with second generation orchard seed for several species in Atlantic Canada (Adams, 2020). In Alberta, only about 15% of seed is obtained from seed orchards, but the percentage increases annually as seed orchards mature and achieve higher production.

8.2. National (or sub-national) strategies, guidelines and recommendations for using forest genetic resources

Forest resources are the responsibility of provincial governments, so resource strategies, guidelines and recommendations are developed and implemented at the provincial and territorial levels. Jurisdictions have developed regulations and policies regarding seed zones and seed transfer rules.

British Columbia's seed regulations and standards apply to all aspects of seed handling, from pricing of seed (weight of seed × price × germination adjustment) (British Columbia Ministry of

Attorney General, 2019) to the minimum number of trees (10) from which seed is collected within a maximum area (radius no more than 8 km) (British Columbia Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2018). The Standards include the process of registering seed lots with the province, the quality requirements of the seed, collection requirement for selected and un-selected seed and vegetative material, registration of parent trees, determining breeding or clonal value, storage and testing, selection and use of seed and vegetative material, and seed transfer. Seed and vegetative material transfer has been modified in British Columbia as of 2018 to account for impacts of climate change. Climate Based Seed Transfer (CBST) rules must be followed so that seedlings or cuttings grown from a registered lot must be planted on the CBST Area of Use identified for the tree species and Seed BEC unit. These guidelines are set out in the "CBST Areas of Use for British Columbia" document, which is associated with the Chief Forester's Standards for Seed Use.

Regulations are also in force in Alberta where tree material used for reforestation must abide by the Standards for Tree Improvement. These rules fall under the Timber Management Regulations as part of the province's Forest Act and cover: material collection, handling, registration and storage; deployment planning, reporting and monitoring; breeding, testing and verification, and; production of controlled parentage materials. The standards are intended to ensure the ecological adaptability, genetic diversity and health of wild and managed forests, while selective tree breeding is valued for the economic benefits realized by increasing productivity. Two types of reforestation materials are recognized in Alberta: Stream 1 materials are collected from un-selected trees and Stream 2 materials are produced by selective breeding (either in seed orchards or by mass vegetative propagation). Regardless of the stream, all seed or cuttings destined for reforestation must be registered with Alberta Sustainable Resource Development. As part of this registration, geographic origin, pedigree, and diversity must be specified.

Both British Columbia and Alberta forbid the use of GMO (genetically modified organism) trees on public lands. In Alberta, non-native tree species are also excluded from reforestation. Both provinces require the use of selected seed (when available) on public land.

The Ontario Tree Seed Transfer policy specifies where seed can be collected and conditions under which it can be transferred. It applies to all planting materials for Ontario's public lands and other areas where provincial government funds are applied to reforestation activities. The policy replaces seed zones and is instead guided by similarity between historic climatic conditions at seed collection sites and projected future climate at the planting area (Ontario Ministry of Natural Resources and Forestry, 2020). Ontario's ecodistricts are used for tracking the seed source and deployment locations, combined with mandatory climate-based seed transfer considerations.

Quebec's seed collection, production and handling are carried out by the Ministry of Forests, Fauna and Parks (Ministère des Forêts, de la Faune et des Parcs) so detailed regulations are not necessary. However, seed transfer rules are applied as in Ontario, with modification to account for climate change.

Seed management guidelines are lacking in Saskatchewan and Manitoba, while the relatively small Maritime provinces are each within one seed zone so seed transfer rules, policies or regulations have not been necessary.

8.3. Sources of forest reproductive material

Seed orchards have been established for all of the major tree species used in commercial forestry. For forest regeneration, about half of reproductive material is sourced from seed orchards in Canada, with the rest coming from wild stands. For restoration purposes, seed is collected only from wild stands.

Wild stand collections for reforestation programmes are regulated and carefully documented, to ensure that seedling deployment will follow jurisdictional seed transfer rules. Seed collected for other purposes, such as restoration, urban planting or other non-commercial forestry uses, is less controlled because no regulatory frameworks currently exist.

8.4. Grant schemes or other incentive mechanisms that promote the use of certain forest reproductive material

Both Alberta and British Columbia have established regulations that mandate the use of selectively bred seed if it is available on public land. No incentive mechanisms currently exist in Canada to guide the use of forest material.

8.5. The role of registered seed stands, seed orchards and other sources in the supply of forest reproductive material

Seed used for forest regeneration is either produced in seed orchards or collected from wild or artificially regenerated stands, and the proportions of each vary among jurisdictions. In British Columbia, which accounts for almost half of the seedlings planted nationally, about 65% of seed used for reforestation is from 40 selectively bred seed orchards, while in Alberta, this proportion is approximately 15%. Both cases involve contributed seeds from privately owned and government-operated seed orchards. In British Columbia, the seed production program includes most of the commercial species in the province, and seed type falls under three classes: “select” seed is selectively bred in seed orchards; “B” class seed is collected from wild stands, and; “B+” seed is sourced from wild stands that are known to have superior provenance.

Ontario has 74 seed orchards under active management. All were established initially with commercial forest production goals. Goals for white pine (*Pinus strobus*) orchards have shifted to genetic conservation due to pressures on white pine habitat in southern Ontario (Boysen, 2019). In addition, five orchards are being established for butternut (*Juglans cinerea*) across southern Ontario as a component of the genetic conservation efforts for that species (Boysen, 2019). Much of the seed required in southern Ontario is for restoration, conservation, urban planting and carbon sequestration and seed for those purposes is collected from wild stands of a wide diversity of species.

In Quebec, a decade ago, 85% of seed for reforestation was produced in at least 80 seed orchards (Petrinovic *et al.*, 2009).

Almost all of the seed required for reforestation (artificial regeneration) in New Brunswick is produced in second generation seed orchards.

8.6. Does the supply of forest reproductive material meet the demand?

The combination of seed orchard production and wild stand collections meet the demand in each jurisdiction at present. Two factors may challenge seed stock availability in the future. Climate change is being taken into account in several jurisdictions, resulting in altered seed zones both for collection and production. The impact of these recent changes on seed supply is not yet clear. Seed needs are also changing. Until recently, the majority of seedlings planted represented relatively few species used for reforestation as part of commercial forestry operations. Increasingly, tree-planting campaigns have focused on restoration, reclamation, or urban greening. For example, a 50 million tree-planting pledge has been made in Ontario, as well as a pledge to plant 2 billion trees across Canada. The species required for restoration and other non-forestry purposes differ from those used in reforestation. For many species, seed sources remain to be secured. To address this issue, the Canadian Forest Service has initiated a tree seed supply and demand study headed by the National Tree Seed Centre.

8.7. Trends in the demand for forest reproductive material

Forest reproductive material is increasingly needed for restoration initiatives, especially in oilfields where restoration is required for degraded land. However, the most significant demand for forest reproductive material remains to meet needs for artificial regeneration after forest harvest. Regeneration is required after harvesting on Canada's Crown land, either by planting or seeding, or via natural regeneration in cases where the harvest area is adequately stocked by naturally regenerated seedlings. Over the past 20 years, 56% of the harvested area has been planted or seeded across Canada, and nearly all the rest was naturally regenerated. The most recent available data on this topic are from 2017 when 572 million seedlings were planted on 396 thousand hectares (Natural Resources Canada 2020). This represents a 7% increase over the 10-year average. The number of trees planted has been generally increasing since 2012, reflecting the slow recovery of the forest sector after the economic recession in 2008 due to increases in forest area affected by wildland fires and mountain pine beetle.

8.8. Certification of the information on forest reproductive material for national (or sub-national) and international trade, and the rules that are used for this purpose

International sales of commercial quantities of seed are certified under the OECD Scheme for the Reproductive Material Moving in International Trade.

8.9. Forest reproductive material exported and/or imported by Canada

No recent statistics are available for quantities of forest tree seed exported from or imported to Canada.

8.10. Organization of Canada's national (or sub-national) tree seed programme, and the main players and stakeholders

The National Tree Seed Centre is operated by Natural Resources Canada at the Atlantic Forestry Centre in Fredericton, New Brunswick. The aim of the National Tree Seed Centre is to collect, process, and store representative seed samples from native trees and shrubs for conservation and research purposes. The Seed Centre currently holds seed from 134 taxonomic units; most of these are distinct species but a few are varieties or hybrids. The number of accessions per species ranges from one to 905 samples.

Information about each accession is publicly available, and includes specific geographic location and germination rate. Stakeholders include the domestic and international researchers who request and use the seed for a wide variety of research projects.

Seed is collected from natural stands mainly by Seed Centre staff, but also by a variety of collaborators including provincial forest service staff, forest industry and Indigenous peoples. Seed testing is carried out on a regular basis, following protocols established by The International Seed Testing Association and the Association of Official Seed Analysts. Most of the seed is stored at -20 degrees Celsius. The Seed Centre also contains a cryogenic unit the stores about 36,000 embryonic axes of the endangered butternut (*Juglans cinerea*).

Each jurisdiction has its own operational seed production and processing facilities, including seed orchards that provide significant proportions of the seed required for multiple species for provincial planting programmes. All provinces have operational standards or guidelines for collecting, processing, testing, storing and thoroughly documenting seedlots for large quantities of seed, in some cases handling tens of millions of individual seeds. Figure 8.1 provides an overview of the production system for selected seed in British Columbia.

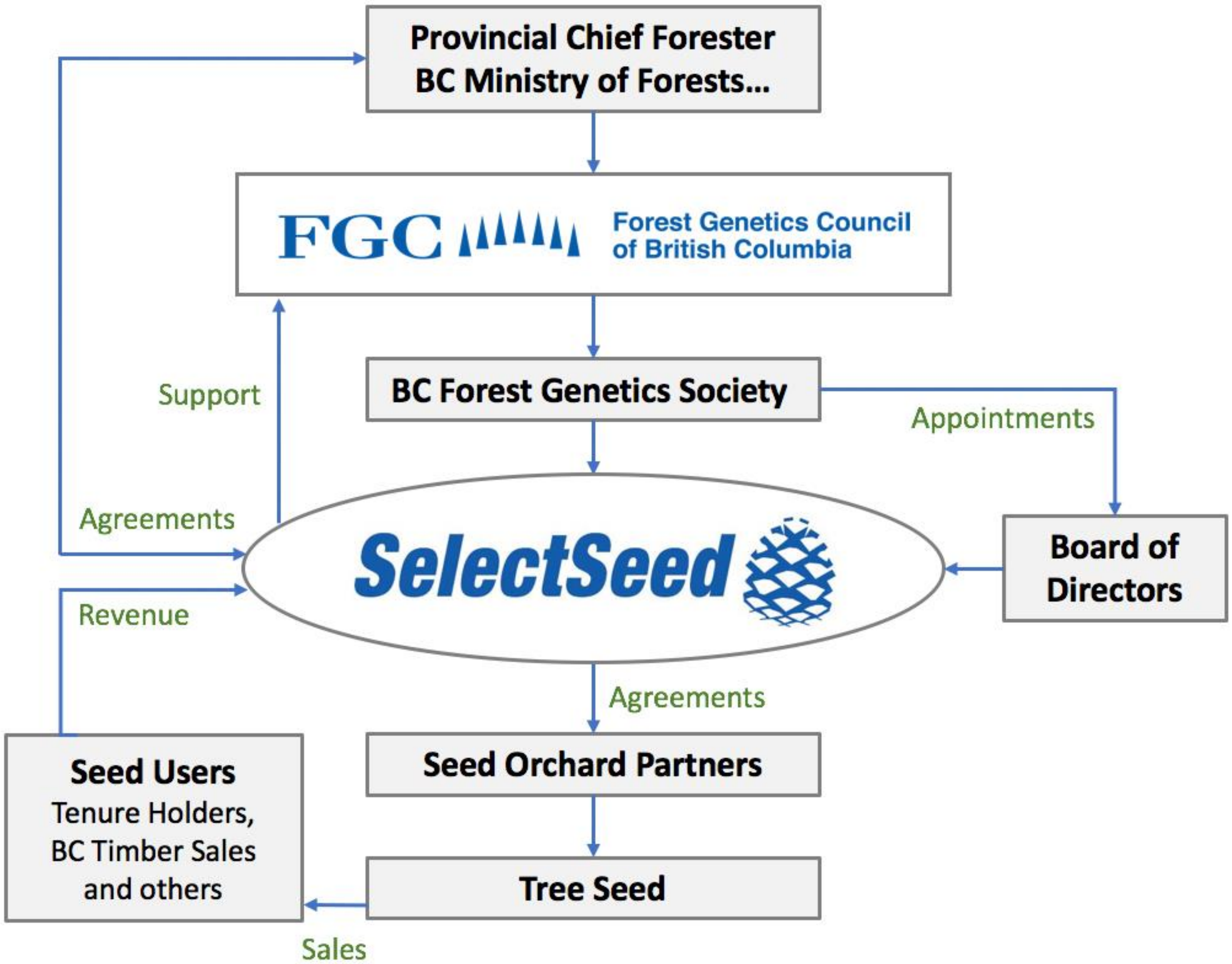


Figure 8.1. Representation of selected seed production in British Columbia (https://www.selectseed.ca/#about).

8.11. Needs, challenges and opportunities for increasing the use of forest genetic resources

Restoration of degraded forest represents a promising application of FGR. A study to assess the seed supply chain for that purpose has been initiated by the National Tree Seed Centre (McPhee, 2020). A challenge for applying genetic resources to restoration is accessing seed from tree and shrub species that are not already being used for artificial regeneration in a commercial forestry context.

Climate change presents a major challenge and opportunity for guided application of FGR. The adoption by several provinces of a climate-based seed transfer approach is now providing a new level of complexity to tree breeding populations, seed orchard composition, and sourcing and deployment of seedlings. Besides these operational challenges, predicting future climate regimes and the tree traits that might best respond to those changes are both areas of ongoing investigation. Breeders proceed based on mean predictions (e.g., breeding value calculations, climate change response surfaces, etc.), yet foresters also have to manage stands to accommodate climatic and broader ecological variance within forest sites. Breeding for multiple traits also poses a challenge which may involve trade-offs between managing forests for overall resilience and promoting traits of importance to the forest industry.

8.12. Priorities for capacity-building and research in this area

All of the jurisdictions are in early stages of climate-based seed transfer approaches. Additional resources are required to address the complexities noted above that accompany these approaches (in some jurisdictions, this will involve re-building previously reduced capacity). In particular, research involving field trials and modelling approaches is needed to help optimize operational changes. This will entail increased training of highly qualified technical and research personnel to address adaptation to climate change, breeding for multiple traits, and expanding our knowledge in these areas for species that have low economic value or low priority in reforestation programs.

Literature Cited

Adams, G. 2020. Tree improvement in Atlantic Canada – Over 40 years and going strong. Tree Seed Working Group News Bulletin, Canadian Forest Genetics Association. No. 69. p. 28-29.

Alberta Government. 2016. Forest Genetic Resource Management and Conservation Standards. Volume 1 – Stream 1 and 2. Forestry Division, Alberta Agriculture and Forestry Edmonton, Alberta, Canada. https://open.alberta.ca/dataset/871d9683-824b-468f-9ab1-f2c3e3da3513/resource/8d39c2df-48aa-43d9-83a1-ad747f24ee2e/download/2016-AlbertaFGRMS-Volume-1-Stream-1-and-Stream-2-FGRMS-Dec2016.pdf

Boysen, B. 2019. 2018-2019 Forest Gene Conservation Association Update. Tree Seed Working Group News Bulletin. Canadian Forest Genetics Association. No. 68, pp 23-27.

British Columbia Ministry of Attorney General. 2019. Forest and Range Practices Act. Tree Seeds and Services Regulation B.C. Reg. 138/2019. Deposited June 24, 2019 and effective July 2, 2019. Consolidated Regulations of British Columbia. Victoria, BC, Canada

British Columbia Ministry of Forests, Lands, Natural Resource Operations and Rural Development. 2018. Chief Forester's Standards for Seed Use. Amendments Established April 5, 2018 with Effective Date of August 6, 2018. Victoria, BC, Canada. https://www2.gov.bc.ca/gov/content/industry/forestry/managing-our-forest-resources/treeseed/legislation-standards/chief-forester-s-standards-for-seed-use

Government of Saskatchewan. 2015. The Forest Resources Management (Saskatchewan Environmental Code Adoption) Regulations. Chapter F-19.1 Reg 11 (effective January 5, 2015). Regina, Saskatchewan, Canada

McPhee, D. 2020. National Tree Seed Centre Update. Tree Seed Working Group News Bulletin. Canadian Forest Genetics Association. No. 69, pp 21-25.

Ontario Ministry of Natural Resources and Forestry. 2020. Ontario Tree Seed Transfer Policy. https://www.ontario.ca/page/ontario-tree-seed-transfer-policy

Petrinovic, J.F., Gélinas, N. and Beaulieu, J., 2009. Benefits of using genetically improved white spruce in Quebec: The forest landowner's viewpoint. The Forestry Chronicle, 85(4), pp.571-582.

Chapter 9. The state of selective breeding programs

9.1. Approaches used for selective tree breeding

Most selective tree breeding is carried out using the classic methods for selection, seed orchard establishment and management, rogueing, and controlled crosses. Most planting material continues to be seedlings produced in seed orchards. However, some planting material is also produced using vegetative propagation methods including rooted cuttings and somatic embryogenesis (SE) (especially in Quebec and New Brunswick).

New technologies aimed at accelerating selection and breeding are gathering momentum. These include genomic analyses to develop marker-assisted selection for a broader assortment of traits than has been applied traditionally. This technology represents a powerful approach, particularly when combined with SE and cryogenic storage methods (Chamberland *et al.*, 2020; Park *et al.*, 2018)

9.2. Uses and traits prioritized in selective tree breeding

The main uses for selective tree breeding are for commercial forestry operations to produce timber. Breeding for insect and disease resistance for species conservation is a growing but secondary goal. The most important specific traits that are the focus of selection and breeding programmes are growth and yield, form, insect and disease resistance, wood quality, and adaptive traits focused on mitigating impacts of climate change.

9.3. Organization of selective tree breeding programmes and main players and stakeholders

Each jurisdiction has its own approach to selective tree breeding because resource management is the responsibility of provinces/territories.

Information on selective tree breeding in British Columbia was obtained from the British Columbia Forest Genetics Council (FGC) (https://www.fgcouncil.bc.ca/). The FGC is appointed by the province's chief forester to advise on matters related to forest genetics including seed production, genetic gain, genetic resource management, and insect and disease problems. Membership of FGC is balanced among stakeholder groups. The co-chairs of FGC are from provincial government and forestry industry. Members include: interior and coastal seed producers; interior seed users from the northern, southern, and coastal regions of the province; the coastal and interior Technical Advisory Committee chairs; one university researcher, and; one scientist from the Canadian Forest Service. The FGC currently has three technical advisory committees (TACs): the Genetic Conservation TAC; Interior TAC, and; Coastal TAC. Species subcommittees also exist within this structure. Prior to 2017, there were three additional TACs: the Decision Support TAC; Seed Transfer TAC, and; Pest Management TAC. The TACs are drawn from the FGC membership and are responsible for identifying priorities and evaluating proposals for funding.

The mandate of the British Columbia FGC is to advise the chief forester and coordinate activities aimed to enhance conservation, resilience, and value of British Columbia's forests.

The FGC is completing its fifth consecutive five-year strategic plan in 2020, building on the forest genetic management that began in the 1960s under the auspices of the Plus Tree Board. The seven objectives described in the strategic plan are: (1) genetic conservation; (2) resilience and climate-based seed transfer; (3) use of select seed for reforestation; (4) increase genetic gain for growth; (5) use of pest resistance seed for reforestation; (6) resources and efficiency, and; (7) monitor and report. The funding to support the plan comes from the Ministry of Forests, Lands and Natural Resource Operations, forest licensees, SelectSeed Ltd., the federal government, and Genome BC. Annual contributions from all sources exceed CAD $13 million.

The FGC oversees coordination between breeding programmes and provincial seed orchards through SelectSeed Ltd.; a not-for-profit company established in 1998 and owned by the British Columbia Forest Genetics Society. SelectSeed's mandate is to produce British Columbia's forests. Seed orchards have been established and managed SelectSeed in partnership with forestry companies. The seed is sold to forest tenure holders and the British Columbia government. Each orchard targets a specific Seed Planning Unit, and each unit is defined for a specific combination of species, seed zone, and elevation. Seed orchards produce most of the select material used in British Columbia, but vegetative production is employed for yellow cypress (*Cupressus nootkatensis*). There are breeding programmes for coastal and interior Douglas-fir, true fir, western redcedar, western hemlock, yellow cypress, lodgepole pine, ponderosa pine, coastal and interior western white pine, interior spruce, western larch and coastal broadleafs.

The Operational Tree Improvement Program (OTIP), a subprogram of the FGC, focuses on increasing the quality and quantity of Class A or Select Seed from provincial and forest industry orchards. It is also an advisory body providing technical support to improve orchard production and management.

Alberta has established a Forest Genetic Resources Council (abtreegene.com), consisting of: stakeholder representatives from provincial government departments responsible for environment and forest management (including one from a genetics program); forest industry (including two with hardwood interests and two with softwood interests), and; research institutions (university and government) representing the fields of conservation biology, forest land reclamation, growth and yield, and forest nurseries. The mandate of the FGR Council is to:

1. provide advice and recommendations to the Government of Alberta on policy, standards, and recommendations related to the management of Alberta's forest genetic resource (FGR);
2. foster communication, dialogue and technology transfer among participants and stakeholders in forest genetics research and operations on public forest lands and wetlands;
3. encourage an interdisciplinary approach to FGR management; and,
4. identify and address issues of concern related to the management of FGR.

Alberta's selective tree breeding is managed through Tree Improvement Alberta in partnership with the province's Forest Health and Adaptation Program. Forest health and Adaptation manages a network of seed orchards at four locations and focused on six tree species. The program works with forest companies on breeding programs aiming to increase timber and pulp production on managed forest land, improve wood mechanical properties, and to identify and increase tolerance to insects, disease, and climatic and weather-related damage (www.alberta.ca). The breeding is organized into breeding regions, each of which has a species-specific breeding plan.

In Ontario, the Ministry of Natural Resources and Forestry (OMNRF) provides policy and operational guidance/coordination on FGR management and seed use in forest management planning, as well as financial support for FGR management programs. The OMNRF conducts applied forest genetics research and their staff support the implementation of the strategic direction for FGR management, seed transfer, modelling, and enhancing resilience. Along wi th the Ministry of Environment Conservation and Parks, OMNRF also leads genetic conservation for species recovery and protection. OMNRF has not directly been involved with any operational selective tree breeding since 2017.

Selective tree breeding in Ontario is carried out by three regional independent industry associations and they apply annually to the OMNRF's Forestry Futures Trust fund. The associations are the Forest Gene Conservation Association in the south, the Northeast Seed Management Association in the northeast, and the Superior Woods Tree Improvement Association in the northwest. Consultation with all of these groups are used for updating polices and changing management direction. Each association sets its own regional priorities and manages programs to meet the FGR management needs for Crown land (Ken Elliott and Melissa Spearing, pers. comm. 2020).

The Quebec government oversees all selective tree breeding and breeding in Quebec, in partnership with forest industry. Research is carried out by scientists at Laval University, the Canadian Forest Service, and the provincial government. Often these groups collaborate directly to research selective tree breeding.

In New Brunswick, there has been an active selective tree breeding programme for over 40 years and the provincial government has a Tree Improvement Section dedicated to providing selectively bred seed for all reforestation on Crown land. Industry are also close collaborators in New Brunswick, and the Canadian Forest Service and the University of New Brunswick have been engaged in research to support the provincial programme. Each of these groups is a member of the New Brunswick Tree Improvement Council. In February 2020, representatives from Atlantic Canadian provincial governments, industry, and the Canadian Forest Service met to discuss the possibilities for better integration of selective tree breeding efforts across the maritime region.

9.4. Current and emerging technologies used in selective tree breeding

Quebec and New Brunswick are planting significant numbers of vegetatively propagated trees, both rooted cuttings and somatic emblings, and they have been testing the efficacy of genomic selection in this process (Chamberland *et al.*, 2020, Park *et al.*, 2016). In New Brunswick, trees have been produced by forest industry (J.D. Irving, Ltd.) using somatic embryogenesis for more than 20 years (Park *et al.* 2016). Combining embryogenic production with genomic selection has resulted in dramatic reduction in the time required for the selective breeding of traits (Adams 2020).

Adaptive traits of trees in general have been studied using a variety of methods, from traditional field studies and response functions, to genomic studies and evaluation of the role that gene copy number plays in adaptive evolution (Prunier *et al.*, 2017; Lu *et al.*, 2014; De La Torre *et al.*, 2014). A literature search revealed 40 new articles describing genetic and genomic studies to advance breeding and selection for 10 tree species. Studies included traditional quantitative analyses of wood quality and growth traits as well as gene discovery studies and the development and testing of methods for genomic selection. By far the greatest number of research has focused on white spruce (*Picea glauca*) across Canada. The basic research on *Picea glauca* described in Chapter 5 of this report served as a foundation for the studies listed in Table 9.1 which are applied to advancing and accelerating trait selection for commercial use. Wood quality has received increased attention because it is expected to reduce the cost of breeding for wood quality traits (Park *et al.*, 2018; Ratcliffe *et al.*, 2017; Beaulieu *et al.*, 2014). Breeding for various traits related to adaptive response to climate change has also received increased attention. White spruce has also been the subject of a number of studies on genetic resistance to pests, via a combination of quantitative and gene expression approaches (Méndez-Espinoza *et al.*, 2018; Mageroy *et al.*, 2015; Lamara *et al.*, 2018; Porth *et al.*, 2012). Gene discovery and other aspects of breeding for disease resistance has also progressed for other species, such as for blister rust resistance in *Pinus monticola* (Liu *et al.*, 2013, 2017, 2019).

Table 9.1. Survey of literature concerning research on selective tree breeding of Canadian tree species since 2012.

Species	**Trait**	**Method**	**Author**
Castanea dentata	Blight resistance	Quantitative analyses	Dale and Galic 2012
Callitropsis nootkatensis	Growth traits	Quantitative analyses	Russell *et al.* 2015
	Growth	Quantitative analyses	Baltunis e*t al.* 2013
	Height	Genomic BLUP	El-Kassaby *et al.* 2012
Picea glauca	Photosynthesis	Quantitative analyses	Benomar *et al.* 2016

Species	Trait	Method	Author
	Wood quality	Quantitative analysis	Park *et al*. 2012
	Adaptive traits	Gene copy number variation	Prunier e*t al*. 2017
	Adaptive traits	Quantitative and genomic analyses – SNP arrays	De La Torre *et al*. 2014
	Seedling characteristics, root growth	Quantitative analysis	Carles *et al*. 2012
	Wood quality	Quantitative genetic analyses	Lenz *et al*. 2013
	Provenance growth performance in response to climate	Quantitative analyses, response function	Lu *et al*. 2014
	Growth, survival	Quantitative analyses	Weng e*t al*. 2019
	Pest resistance	Quantitative genetic analyses of resistance biomarkers	Méndez-Espinoza *et al*. 2018
	Tree height, wood density	Pedigree and single-step genomic evaluation	Ratcliffe *et al*. 2017
	Spruce budworm resistance	Gene discovery	Mageroy *et al*. 2015
	Spruce budworm resistance	Association genetics	Lamara *et al*. 2018
	Height, stem form, survival, bud dormancy, branching	Clonal heritability	Wahid *et al*. 2012
	Height, wood quality		El-Dien *et al*. 2016
	Genomic selection	Economic analyses	Chamberland *et al*. 2020
	Seedling physiology and morphology	Quantitative analyses	Carles *et al*. 2015
	Insect resistance	Genetical genomics	Porth *et al*. 2012
	Growth, volume	Genomic selection	Park *et al*. 2018
	Growth, wood quality	Genomic selection	Beaulieu *et al*. 2014
	Genomic markers (informative SNPs	Traceability of elite germplasm in somatic plant production	Godbout e*t al*. 2017
	Height, diameter	Quantitative analyses	Wahid *et al*. 2013
	Height, diameter	Quantitative analyses	Wahid *et al*. 2012
	Growth	Quantitative analyses	Weng *et al*. 2012

Species	Trait	Method	Author
Picea glauca x *P. engelmannii*	Tree height	Genomic (SNPs)and Quantitative	Ratcliffe *et al*. 2015
	Tree height, wood density	Genomic (SNPs) and Quantitative	El-Dien *et al*. 2018
Picea mariana	Growth and wood traits	Genomic selection (SNPs)	Lenz *et al*. 2017
	Growth and stem forking	Quantitative analyses	Wang *et al*. 2018
	EST resource for molecular breeding, etc.	EST analyses	Mann *et al*. 2013
	Seed production	Breeding techniques	Colas, Lamhamedi, 2014
Picea abies	Insect resistance	Quantitative analyses	Mottet *et al*. 2015 .
Pinus monticola	Blister rust resistance	Marker assisted selection	Liu *et al*. 2019
	Blister rust resistance	Marker assisted selection	Liu *et al*. 2017
	Blister rust resistance	Marker assisted selection	Liu *et al*. 2013
Pinus contorta	Growth and wood quality traits	Marker assisted selection	Ukrainetz, Mansfield, 2020
Populus tremuloides	Growth	Clonal selection	Gylander *et al*. 2012
Tsuga heterophylla	Height	Spatial analyses	Cappa *et al*. 2015

9.5. Quantity of tree germplasm that is transferred within and outside of the country for research and development purposes

The National Tree Seed Centre (NTSC) located in Fredericton, New Brunswick, is the main source of tree seed that is shared for research purposes both within and outside of Canada. In 2019, the NTSC responded to 50 seed requests, sending seed to researchers in Canada (nine provinces), the USA (two states), and Portugal. In total, over 6.5 million seeds from 520 source-identified and quality-tested seedlots, representing 60 tree species, were provided to domestic and international researchers.

9.6. Access and benefit-sharing

There have been no significant changes in access and benefit sharing (ABS) at the national level since Canada's 2012 FGR Report. Canada has not yet become a signatory to the Nagoya Protocol and sub-national jurisdictions vary in their approaches to ABS. Alberta, for example, has developed standards for provincial Crown land that are recognised by provincial government regulations and that include access to genetic material and benefit sharing. The standards stipulate that all genetic resources collected from public land in Alberta require prior and informed consent from the provincial government, and that all material used for commercial purposes other than fiber production in Alberta could be subject to a benefit-sharing agreement in which the province would receive revenue or material transfer. Payment to the province for genetic material does not apply when the material is used for operational deployment of trees and shrubs in Alberta, or for strengthening provincial genetic selective tree breeding programs. A Material Transfer Agreement (MTA) may be required, on a case by case basis, for exchanges of FGR between Alberta and other jurisdictions or between Alberta and other entities (e.g., industrial, academic or research organizations).

9.7. Needs, challenges and opportunities for selective tree breeding

Selective tree breeding have always been well supported in at least some jurisdictions, such as British Columbia and New Brunswick, where the forest industry has been an active participant and has realised significant gains from the provincial programs. In other jurisdictions, obtaining sufficient resources continues to present a challenge. Consequently, increased capacity for running selective tree breeding programmes at the jurisdictional level is a need for most provinces and territories. This is particularly acute as provinces move to climate-based seed transfer approaches while second and third-generation seed orchards are in progress. Expanded capacity for establishing, testing, and maintain advanced generation seed orchards is needed, as well as highly qualified personnel to carry out the modelling, genomics, field tests, and collection and deployment planning under the new climate-based seed transfer rules.

Some current seed orchards are experiencing challenges with respect to seed production, especially for lodgepole pine (*Pinus contorta*), where demand has outstripped production capacity due to lower than predicted seed set in most orchards. As a result, orchards must be expanded or other solutions implemented to meet these demands. The sheer size and ecosystem diversity of most Canadian jurisdictions present significant challenges for production capacity in general. The quantity of seedlings required annually for reforestation and, in some cases, for restoration, is in the hundreds of millions, and seed orchards have not yet been established to meet the expanded list of tree species and desired trait profiles (e.g., for well-adapted trees under changing climate conditions). Beyond commercially important species, basic genetic and genomic information is typically lacking or available for only a small subset of relevant environmental conditions or locations.

Rapid advances in marker-assisted and genomic selection tools present valuable opportunities for advancing our understanding and use of FGR. Further, tool developed for one species using these technologies may show at least partial transferability to others. Several forestry companies are currently consolidating and their larger size should make the marginal cost of selective tree breeding programmes more attractive. Notably, it is currently difficult to make progress without financial involvement of forest industry. Yet growing interest in land reclamation and ecosystem restoration along with a growing awareness of the importance of species and seed source considerations offers opportunities to raise the profile of breeding programmes beyond traditional commercial selective tree breeding applications.

9.8. Priorities for capacity-building and research

Research to understand genetic basis and patterns of diversity in traits including drought resistance, pest and disease resistance, and wood properties is a priority for several jurisdictions. Existing advanced generation seed orchards, which were constituted for specific climatic zones and multiple trait selection with increasing emphasis on adaptive traits, are well-suited for these applications, as well as to currently evolving climate-based seed transfer approaches. However, this connection calls for increased investment in capacity building and research. In particular, the technologies noted above present new challenges for managing large quantities of data.

Literature Cited

Adams, G. 2020. Tree improvement in Atlantic Canada – Over 40 years and going strong. Tree Seed Working Group News Bulletin, Canadian Forest Genetics Association. No. 69. p. 28-29.

Baltunis, B.S., Russell, J.H., Van Niejenhuis, A., Barker, J. and El-Kassaby, Y.A., 2013. Genetic analysis and clonal stability of two yellow cypress clonal populations in British Columbia. Silvae Genetica, 62(1-6), pp.173-186.

Beaulieu, J., Doerksen, T., Clément, S., MacKay, J. and Bousquet, J., 2014. Accuracy of genomic selection models in a large population of open-pollinated families in white spruce. Heredity, 113(4), pp.343-352.

Benomar, L., Lamhamedi, M.S., Rainville, A., Beaulieu, J., Bousquet, J. and Margolis, H.A., 2016. Genetic adaptation vs. ecophysiological plasticity of photosynthetic-related traits in young *Picea glauca* trees along a regional climatic gradient. Frontiers in plant science, 7, p.48.

Cappa, E.P., Yanchuk, A.D. and Cartwright, C.V., 2015. Estimation of genetic parameters for height using spatial analysis in *Tsuga heterophylla* full-sibling family trials in British Columbia. Silvae Genetica, 64(1-6), pp.59-73.

Carles, S., Boyer Groulx, D., Lamhamedi, M.S., Rainville, A., Beaulieu, J., Bernier, P., Bousquet, J., Deblois, J. and Margolis, H.A., 2015. Family Variation in the Morphology and Physiology of White Spruce (*Picea glauca*) Seedlings in Response to Elevated CO2 and Temperature. Journal of Sustainable Forestry, 34(3), pp.169-198.

Carles, S., Lamhamedi, M.S., Beaulieu, J., Stowe, D.C. and Margolis, H.A., 2012. Genetic parameters of morphological and physiological characteristics of containerized white spruce (*Picea glauca* [Moench.] Voss) seedlings. Tree genetics & genomes, 8(1), pp.39-51.

Chamberland, V., Robichaud, F., Perron, M., Gélinas, N., Bousquet, J. and Beaulieu, J., 2020. Conventional versus genomic selection for white spruce improvement: a comparison of costs and benefits of plantations on Quebec public lands. Tree Genetics & Genomes, 16(1), pp.1-16.

Colas, F. and Lamhamedi, M.S., 2014. Production of a new generation of seeds through the use of somatic clones in controlled crosses of black spruce (*Picea mariana*). New forests, 45(1), pp.1-20.

Dale, A. and Galic, D., 2012, September. Breeding blight resistant American chestnut for Canada. In V International Chestnut Symposium 1019 (pp. 49-53).

De La Torre, A.R., Wang, T., Jaquish, B. and Aitken, S.N., 2014. Adaptation and exogenous selection in a *Picea glauca* × *Picea engelmannii* hybrid zone: implications for forest management under climate change. New Phytologist, 201(2), pp.687-699.

Gylander, T., Hamann, A., Brouard, J.S. and Thomas, B.R., 2012. The potential of aspen clonal forestry in Alberta: breeding regions and estimates of genetic gain from selection. PloS one, 7(8).

El-Dien, O.G., Ratcliffe, B., Klápště, J., Porth, I., Chen, C. and El-Kassaby, Y.A., 2018. Multienvironment genomic variance decomposition analysis of open-pollinated Interior spruce (*Picea glauca* x *engelmannii*). Molecular breeding, 38(3), p.26.

El-Dien, O.G., Ratcliffe, B., Klápště, J., Porth, I., Chen, C. and El-Kassaby, Y.A., 2016. Implementation of the realized genomic relationship matrix to open-pollinated white spruce family testing for disentangling additive from nonadditive genetic effects. G3: Genes, Genomes, Genetics, 6(3), pp.743-753.

El-Kassaby, Y.A., Klápště, J. and Guy, R.D., 2012. Breeding without breeding: selection using the genomic best linear unbiased predictor method (GBLUP). New Forests, 43(5-6), pp.631-637.

Godbout, J., Tremblay, L., Levasseur, C., Lavigne, P., Rainville, A., Mackay, J., Bousquet, J. and Isabel, N., 2017. Development of a traceability system based on a SNP array for large-scale production of high-value White Spruce (*Picea glauca*). Frontiers in plant science, 8, p.1264

Lamara, M., Parent, G.J., Giguère, I., Beaulieu, J., Bousquet, J. and MacKay, J.J., 2018. Association genetics of acetophenone defence against spruce budworm in mature white spruce. BMC plant biology, 18(1), p.231.

Lenz, P., Auty, D., Achim, A., Beaulieu, J. and Mackay, J., 2013. Genetic improvement of white spruce mechanical wood traits—early screening by means of acoustic velocity. Forests, 4(3), pp.575-594.

Lenz, P.R., Beaulieu, J., Mansfield, S.D., Clément, S., Desponts, M. and Bousquet, J., 2017. Factors affecting the accuracy of genomic selection for growth and wood quality traits in an advanced-breeding population of black spruce (*Picea mariana*). BMC genomics, 18(1), p.335.

Liu, J.J., Hammett, C. and Sniezko, R.A., 2013. *Pinus monticola* pathogenesis-related gene PmPR10-2 alleles as defense candidates for stem quantitative disease resistance against white pine blister rust (*Cronartium ribicola*). Tree genetics & genomes, 9(2), pp.397-408.

Liu, J.J., Sniezko, R.A., Zamany, A., Williams, H., Wang, N., Kegley, A., Savin, D.P., Chen, H. and Sturrock, R.N., 2017. Saturated genic SNP mapping identified functional candidates and selection tools for the *Pinus monticola* Cr2 locus controlling resistance to white pine blister rust. Plant biotechnology journal, 15(9), pp.1149-1162.

Liu, J.J., Williams, H., Zamany, A., Li, X.R., Gellner, S. and Sniezko, R.A., 2019. Development and application of marker-assisted selection (MAS) tools for breeding of western white pine (*Pinus monticola* Douglas ex D. Don) resistance to blister rust (*Cronartium ribicola* JC Fisch.) in British Columbia. Canadian Journal of Plant Pathology, pp.1-10.

Lu, P., Parker, W.H., Cherry, M., Colombo, S., Parker, W.C., Man, R. and Roubal, N., 2014. Survival and growth patterns of white spruce (*Picea glauca* [Moench] Voss) rangewide provenances and their implications for climate change adaptation. Ecology and Evolution, 4(12), pp.2360-2374.

Mageroy, M.H., Parent, G., Germanos, G., Giguère, I., Delvas, N., Maaroufi, H., Bauce, É., Bohlmann, J. and Mackay, J.J., 2015. Expression of the β-glucosidase gene Pgβglu-1 underpins natural resistance of white spruce against spruce budworm. The Plant Journal, 81(1), pp.68-80.

Mann, I.K., Wegrzyn, J.L. and Rajora, O.P., 2013. Generation, functional annotation and comparative analysis of black spruce (*Picea mariana*) ESTs: an important conifer genomic resource. BMC genomics, 14(1), p.702.

McPhee, D. 2020. National Tree Seed Centre Update. Tree Seed Working Group News Bulletin, Canadian Forest Genetics Association. No. 69, pp 21-25.

Méndez-Espinoza, C., Parent, G.J., Lenz, P., Rainville, A., Tremblay, L., Adams, G., McCartney, A., Bauce, É. and MacKay, J., 2018. Genetic control and evolutionary potential of a constitutive resistance mechanism against the spruce budworm (*Choristoneura fumiferana*) in white spruce (*Picea glauca*). Heredity, 121(2), pp.142-154.

Mottet, M., DeBlois, J. & Perron, M. 2015. High genetic variation and moderate to high values for genetic parameters of *Picea abies* resistance to *Pissodes strobi*. Tree Genetics & Genomes 11, 58.

Park, Y.S., Ding, C., Lenz, P., Nadeau, S., Adams, G., Millican, S., Beaulieu, J. and Bousquet, J., 2018. Implementing genomic selection for multi-varietal forestry of white spruce (*Picea glauca*) in New Brunswick, Canada. Clonal Trees in the Bioeconomy Age: Opportunities and Challenges.

Park, Y.S., Beaulieu, J. and Bousquet, J., 2016. Multi-varietal forestry integrating genomic selection and somatic embryogenesis. Vegetative propagation of forest trees, pp.302-322.

Park, Y.S., Weng, Y. and Mansfield, S.D., 2012. Genetic effects on wood quality traits of plantation-grown white spruce (*Picea glauca*) and their relationships with growth. Tree genetics & genomes, 8(2), pp.303-311.

Porth, I., White, R., Jaquish, B., Alfaro, R., Ritland, C. and Ritland, K., 2012. Genetical genomics identifies the genetic architecture for growth and weevil resistance in spruce. PLoS One, 7(9).

Prunier, J., Caron, S., Lamothe, M., Blais, S., Bousquet, J., Isabel, N. and MacKay, J., 2017. Gene copy number variations in adaptive evolution: The genomic distribution of gene copy number variations revealed by genetic mapping and their adaptive role in an undomesticated species, white spruce (*Picea glauca*). Molecular ecology, 26(21), pp.5989-6001.

Ratcliffe, B., El-Dien, O.G., Cappa, E.P., Porth, I., Klápště, J., Chen, C. and El-Kassaby, Y.A., 2017. Single-step BLUP with varying genotyping effort in open-pollinated *Picea glauca*. G3: Genes, Genomes, Genetics, 7(3), pp.935-942.

Ratcliffe, B., El-Dien, O.G., Klápště, J., Porth, I., Chen, C., Jaquish, B. and El-Kassaby, Y.A., 2015. A comparison of genomic selection models across time in interior spruce (*Picea engelmannii* × *glauca*) using unordered SNP imputation methods. Heredity, 115(6), pp.547-555.

Russell, J.H., Costa e Silva, J. and Baltunis, B.S., 2015. Multisite genetic parameter estimates from a *Callitropsis nootkatensis* diallel study with clonally replicated progeny. Canadian Journal of Forest Research, 45(6), pp.689-697.

Ukrainetz, N.K. and Mansfield, S.D., 2020. Assessing the sensitivities of genomic selection for growth and wood quality traits in lodgepole pine using Bayesian models. Tree Genetics & Genomes, 16(1), p.14.

Wahid, N., Lamhamedi, M.S., Rainville, A., Beaulieu, J. and Margolis, H.A., 2013. Genetic control and nursery-plantation genotypic correlations for growth characteristics of white spruce somatic clones. Journal of sustainable forestry, 32(6), pp.576-593.

Wahid, N., Lamhamedi, M.S., Beaulieu, J., Margolis, H.A. and Deblois, J., 2012. Genetic parameters and clonal variation in growth and nutritional traits of containerized white spruce somatic seedlings. Acta botanica gallica, 159(3), pp.373-384.

Wahid, N., Rainville, A., Lamhamedi, M.S., Margolis, H.A., Beaulieu, J. and Deblois, J., 2012. Genetic parameters and performance stability of white spruce somatic seedlings in clonal tests. Forest ecology and management, 270, pp.45-53.

Wang, J.J., Weng, Y.H., Krasowski, M., Yan, G.H. and Fullarton, M., 2018. Genetic parameters of growth and stem forking for black spruce progeny tested in New Brunswick, Canada. New forests, 49(2), pp.265-277.

Weng, Y., Charrette, P. and Lu, P., 2019. Re-examining breeding zones of white spruce in northwestern Ontario, Canada. New Forests, 50(5), pp.845-858.

Weng, Y., Park, Y.S. and Lindgren, D., 2012. Unequal clonal deployment improves genetic gains at constant diversity levels for clonal forestry. Tree genetics & genomes, 8(1), pp.77-85.

Chapter 10. Management of forest genetic resources

10.1. Taking genetic considerations into account, at a practical level, in managing natural and planted forests, as well as other wooded lands

The forest industry has paid increasing attention to genetic diversity in recent years, both in terms of improvement potential for tree breeding and conservation of genetic resources. This trend may result from the growing recognition that genetic diversity is essential for adaptation to environmental pressures such as climate change, invasive species, or endemic pests and diseases. Interest in carbon capture has also increased, and practitioners are aware that fast growing trees (including selectively bred varieties) will capture more carbon than slower growing trees.

Increasingly, seed used for plantation establishment is assessed for diversity and performance in plantations (especially in British Columbia, Alberta, Ontario, and Quebec). The role of industry in identifying the seed orchard lot required for reforestation depends in part on which organization oversees selective tree breeding programs within a given jurisdiction. As plantations grow in size, the accumulated data that is collected for tracking the site-specific performance of individual species will provide the knowledge required for adaptive management to the pressures noted above.

Sustainable forest management is considered to encompass genetic resources as a component of biodiversity. Canada is a leader in sustainable forest management, with 168 million hectares certified to third party standards in 2019, although standards for management of forest genetic resources (FGR) are not typically detailed in certification schemes.

10.2. Current and emerging technologies used in the management of forest genetic resources

The most significant recent development in the management of FGR is the switch from geographically-based to climate-based seed transfer (CBST) rules. This approach is already practised in British Columbia, Alberta, Ontario and Quebec. While approaches vary across provinces, all provinces share the objective of increasing the likelihood that planted seedlings will be adapted to local climate conditions upon maturity.

In British Columbia, it has been determined that within the context of climate and genetic suitability, many seedlots have an expanded seed deployment area compared with 20 or more years ago (British Columbia Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2019). These expanded deployment areas are termed “areas of use” The extent to which the areas of use are expanded depends on the breadth of the climate space within British Columbia that is occupied by seed source trees. Latitude and elevation are used in determining the allowable distance from source to area of use.

The transition to CBST in British Columbia is expected to take several years in order to mitigate impacts to seed producers and users, to fully develop policy, and to implement information management systems and decision support tools. During the transition period, seed users who aim to maximize productivity must follow provincial policy by using CBST and selected seed with highest available genetic gain. When that is not possible, the use of geographically-base seed zone selected seed with the highest genetic gain is permitted. If no selectively bred seed is available for a given planting site, an alternative option is to use CBST with registered wild stand collection seed. Finally, if neither CBST information or selectively bred seed are available for the species and site of interest, registered seed collected from the same seed zone may be used. A newly developed CBST "Area of Use" tool is used with a "Seedlot Selection Tool" to assist practitioners in identifying planting sites and selecting planting material for the sites. These tools are able to incorporate real time data on seed inventory balances as the seedlot data are expanded and updated.

Ontario has also developed policy pertaining to climate-based seed transfer, based on a collaboration between Natural Resources Canada and the Ontario Ministry of Natural Resources and Forestry. The new policy has been introduced in the updated Forest Operations and Silviculture Manual, where it outlines requirements to match climate at seed collection sites with projected future climate at deployment sites and to revisit genetic field trials to assess risks (van Kerkhof, 2019).

10.3. The main actors/ stakeholders for managing natural and planted forests, as well as other wooded lands at national (or sub-national) levels

Provincial and territorial governments are ultimately responsible for most of the forest land in Canada, but the entities who manage production forests on the ground are generally companies that have long-term licenses or agreements for specific areas or for a specific annual allowable cut (AAC). These are all stakeholders in Canada's forest land (Table 10.1).

Table 10.1. Public forest land managed by forestry companies through long-term licenses or other forest management agreements, listed by province.

Province	Total area of forest	% provincial crown	No. licensees	No. of forest licenses or agreements	Total area of licenses (ha)
Newfoundland and Labrador	23,227,200	96	1		1,400,000
Nova Scotia	4,275,000	47	12		604,000
Prince Edward Island	265,000	12	N/A	N/A	N/A
New Brunswick	6,091,000	48	5	10	3,272,505
Quebec	76,100,000	92	40 management panels	70 management units	28,200,000

Province	Total area of forest	% provincial crown	No. licensees	No. of forest licenses or agreements	Total area of licenses (ha)
Ontario	71,100,000	90		77 management units	28,516,771
Manitoba	36,300,000	95	2	+ volume based licences	11,400,000
Saskatchewan	29,585,627	91	5		5,271,039
Alberta	35,200,000	93	10	20	23,400,000
British Columbia	57,910,000	94	Approx. 180	280 large and medium	22,000,000
Northwest Territories	80,000,000	87	1		1,556,500
Yukon	27,000,000	85			
Nunavut	815,000				

https://www.sfmcanada.org/images/Publications/EN/SK_info_Provinces_and_territories_EN.pdf;https://www.sfmcanada.org/images/Publications/EN/NWT_info_Provinces_and_territories_EN.pdf;https://www.sfmcanada.org/images/Publications/EN/YK_info_Provinces_and_territories_EN.pdf;https://www.sfmcanada.org/images/Publications/EN/Manitoba_info_Provinces_and_territories_EN.pdf;https://www.sfmcanada.org/images/Publications/EN/Ontario_info_Provinces_and_territories_EN.pdf;https://www.sfmcanada.org/images/Publications/EN/BC_info_Province_and_territories_EN.pdf;https://www.sfmcanada.org/images/Publications/EN/AB_info_Provinces_and_territories_EN.pdf;https://www.sfmcanada.org/images/Publications/EN/QC_info_Provinces_and_territories_EN.pdf;https://www.sfmcanada.org/images/Publications/EN/New_Brunswick_info_Provinces_and_territories_EN.pdf;https://www.sfmcanada.org/images/Publications/EN/Nova_Scotia_info_Provinces_and_territories_EN.pdf;https://www.sfmcanada.org/images/Publications/EN/NL_info_Provinces_and_territories_EN.pdf.

Although the ultimate responsibility for Crown land resource management lies with the government of each province, many large and small industrial forestry actors (Table 10.2) also have significant responsibilities within the context of their licence or agreement. In Alberta, for example, when companies enter into Forest Management Agreements (FMA) they are required to not only develop Forest Management Plans for the FMA area, but also to: carry out the research necessary to support their forest management objectives; conduct a timber supply analysis; maintain inventories, and; ensure adequate public involvement and consultation. The companies must also follow the laws, policies, and regulations of the Province of Alberta and the terms of the FMA. Among these responsibilities is the need to ensure that the trees to be planted match seed source at the intended planting site.

In British Columbia, forest divisions must prepare forest stewardship plans that describe how they will meet provincial government objectives for 11 resource values including soils, timber, wildlife, water quality, fish/riparian, biodiversity, visual quality, recreation and cultural heritage. They must also solicit and consider public and Indigenous peoples' comments.

Most jurisdictions do not have forest regulations pertaining to private forest land. However, in British Columbia, where about 5% of the forest land is privately owned, more than 908,000 ha are classified as Managed Forest. All of the estimated 20,000 private forest owners with land designated as managed forest in British Columbia must apply forest practices in accordance with the Private Managed Forest Land Act and associated regulations. That policy outlines forest practices related to soil conservation, protection of water quality, protection of fish habitat, and reforestation (including ensuring use of genetically adapted seed sources).

The Maritime provinces on the east coast have higher proportions of privately owned land than the other provinces and much of the private forest land is in the form of small woodlots. Woodlot owner associations provide support, expertise and some degree of coordination, but the values and objectives of woodlot owners vary with respect to resource management approaches and, in particular, genetic resources.

Table 10.2 Some of the main corporate actors that manage forest land in Canada.

Company name	**Location**	**Area managed**	**Products**	**Species**	**Management role**
A&A Trading Ltd	British Columbia	143,163m^3 AAC	lumber	Spruce	Forest license
Acadian Timber Corp.	New Brunswick	307,965 ha	lumber	66% Softwood 34% Hardwood	Freehold and forest license
Alberta Newsprint Company	Alberta	374,000 ha	Newsprint	Pine, spruce, fir	Forest Management Agreement (FMA)
Alberta-Pacific Forest Industries Inc.	Alberta	6.37 million ha	pulp, renewable energy, biomethanol	Trembling aspen, balsam poplar	FMA Conducts poplar breeding program
ANC Timber	Alberta	373,698 ha	Pulp and paper		FMA
Andersen Pacific Forest Products	British Columbia	50,000 ha	lumber	Hemlock, spruce, Douglas-fir, cedar	Tree Farm Licence (TFL)
Apollo Forest Products Ltd.	British Columbia	Volume-based: 216,746m^3 AAC	lumber	Softwood	Partnership agreement with the

Company name	Location	Area managed	Products	Species	Management role
					Nak'azdli First Nation
ATCO Wood Products	British Columbia	135,000 ha	veneer, logs, chips, biomass	Softwood	Licences; plants 1 million+ trees/year; research
AV Group	New Brunswick	647,500 ha	dissolving grade hardwood pulp (viscose)	Hardwood	Manages 2 Crown land licences; freehold
Babine Forest Products Ltd	British Columbia	449,699m^3 AAC	lumber		Forest license
Blue Ridge Lumber	Alberta	661,085 ha	Lumber, fibreboard	Lodgepole pine, white & black spruce	FMA
C. & C. Wood Products Ltd	British Columbia	68,130 m^3 AAC	Specialty lumber	Softwood	Forest license
Canada Resurgence Development Ltd	British Columbia	291,712 m^3 AAC	lumber		Forest license
Canadian Kraft Paper	Manitoba	1,641,216 m^3 AAC	Pulp & paper	Spruce, pine, fir	Forest Management Licence
Canfor Corporation (Canadian Forest Products Ltd)	British Columbia, Alberta	644,684 ha (Alberta) 9,902,317 m^3 AAC (BC)	lumber, pulp & paper, bioenergy	Softwood, hardwood	FMA, License; manage specifically for genetic diversity
Carrier Lumber	British Columbia, Alberta, Saskatchewan	471,142m^3 AAC	lumber		Forest license
Canoe Forest Products	British Columbia	322,610m^3 AAC	plywood, logs	Softwood	Forest license
Cheslatta Carrier Nation	British Columbia	25,000 ha	lumber		Forest license
Chetwynd Mechanical Pulp ltd.	British Columbia	128,141m^3 AAC	pulp		Forest license

Company name	Location	Area managed	Products	Species	Management role
Commonwealth Plywood	Quebec	25,000,000 ha	plywood, veneer, lumber	Pine, birch, maple oak	25 year agreements
Conifex Timber Inc.	British Columbia	632,500	lumber, renewable energy	Spruce, pine, fir	TSA
Corner Brook Pulp and Paper Ltd.	Newfoundl and and Labrador	1.5 million ha	pulp & paper	Spruce, fir	
Daishowa-Marubeni International Ltd.	British Columbia, Alberta	1.7 million ha	kraft pulp	Softwood hardwood	FMAs, FMUs
Domtar (now EACOM in eastern Canada)	British Columbia, Ontario, Quebec	726,779 ha Quebec, Ontario	printing & specialty papers, softwood & hardwood pulp	Softwood, hardwood	Licences
Downie Timber Ltd. and Selkirk Cedar	British Columbia	183,000 m^3	lumber, logs	Cedar, hemlock, spruce, fir	Forest licences
Dunkley Lumber Ltd.	British Columbia, Alberta	1.3 million m^3	lumber	Spruce, pine, fir	Forest licences
Hampton Affiliates	British Columbia	120,000 ha	lumber	Spruce, pine	Forest licence
Interfor Corporation	British Columbia	1.3 million ha	lumber	Spruce, fir, pine	Forest Licences
Island Timberlands an d Timberwest	British Columbia	500,000 ha	logs	Spruce, fir, hemlock	Forest licences
J.D. Irving, Limited	New Brunswick, Nova Scotia	2.4 million ha	softwood and hardwood lumber	Black, white spruce, jack pine	1.29 freehold, 1.13 license NB
J.H. Huscroft Ltd.	British Columbia	78,644m^3	lumber	Spruce, fir, hemlock, pine	Forest licence
Kruger Inc.	British Columbia, Alberta,		paper and packaging products, energy	softwood	Licences

Company name	Location	Area managed	Products	Species	Management role
	Quebec, Ontario, NL				
La Crete Sawmills Ltd., Tolko Industries Ltd., Norbord Inc.	Alberta	3,017,400 m^3	lumber, pellets;	spruce, aspen	Forest licence
Lecours Lumber Co. Ltd.	Ontario	476,000 m^3	lumber	softwood	Sustainable Forest License agreements
Ledcor Forestry	British Columbia	9,000,000 m^3	logs, lumber, chips, hog fuel	Spruce, pine	Forest licences
LP Building Products	British Columbia, Manitoba, Quebec	5.3 million ha	framing, panels, siding	softwood	Forest Management Licence
Lulumco Inc.	Quebec		lumber	softwood	Licence
Manning Diversified Forest Products Ltd.	Alberta	930,521 ha	lumber		FMA
Mercer Peace River Pulp Ltd	Alberta	2,662,426 ha	Kraft pulp	Aspen, softwood	FMA
Mill & Timber	British Columbia		lumber	western red cedar	
Millar Western Forest Products	Alberta	440,667 ha	lumber, pulp		FMA
Mistik management Ltd	Saskatchewan	1,900,000 ha		softwood	FMA
Northcrest Forest Products	British Columbia		lumber		
Northern Pulp Nova Scotia Ltd	Nova Scotia	250,000 ha	pulp	softwood	License and freehold (owns tree nursery)
Northland Forest Products Ltd.	Alberta		lumber, wood chips, wood residues		

Company name	Location	Area managed	Products	Species	Management role
Port Hawksbury Paper	Nova Scotia	523,000 ha	Pulp and paper		License
Resolute Forest Products	Ontario, Quebec	11.2 million m^3	lumber, panels, paper products, market pulp, pellets	Softwood	Forest licences
Revelstoke Community Forest Corp.	British Columbia	120,000-ha	logs	Softwood	Tree Farm Licence
Sakaw	Saskatchewan	3,300,000 ha		Softwood	FMA
Sinclar Group Forest Products Ltd.	British Columbia		lumber		
Spray Lake Sawmills	Alberta	284,307 ha	lumber		FMA
Sundre Forest Products Ltd	Alberta	553,298 ha	Veneer, lumber		FMA
Taan Forest	British Columbia		lumber, logs, poles	Western Red and yellow Cedar, Sitka Spruce, Western Hemlock	
TimberWest	British Columbia		logs		
Tolko Industries Ltd.	British Columbia, Alberta, Saskatchewan, Manitoba	4,531,403 ha Alberta 200,000 ha Sask.	lumber, veneer, plywood, OSB, and kraft papers	Softwood, hardwood	FMA
West Chilcotin Forest Products Ltd.	British Columbia		lumber		
Western Forest Products Inc.	British Columbia	6.2 million m^3	lumber, pulp	Softwood	Forest licence, Tree Farm Licence

Company name	Location	Area managed	Products	Species	Management role
West Fraser Timber Co. Ltd. (recently purchased Norbord Inc.)	British Columbia		lumber, panels, pulp, papers, residues, treated wood	Softwood and hardwood	Multiple FMAs and other types of licences
WestRock	BC, Alberta, Saskatchewan, Manitoba, Ontario, Quebec		consumer & corrugated packaging, paperboard		
Woodco Industries Ltd.	British Columbia		rough cut timbers; crane mats, bridge modules	Douglas-fir, western hemlock, spruce-pine-fir	
Weyerhaeuser	BC, Alberta, Saskatchewan, Manitoba, Ontario	2,020,000 ha (Saskatchewan)	lumber, engineered wood, OSB		FMA

10.4. Needs, challenges and opportunities for improving the management of forest genetic resources

There is a need for development of FGR inventories for use by forest managers, in particular that pertaining to adaptation and resilience. There is also a need for development of assessment methods such as genetic markers to rapidly identify valuable genetic resources across multiple species (both rare and abundant, angiosperm and gymnosperm) in the context of forest management under changing environmental pressures. Finally, there is a general need for increased general awareness of the importance of FGR in forest resource management via incorporation of FGR principles in forest management courses.

10.5. Priorities for capacity-building and research in this area

An important capacity development priority is training of forest managers in the use of climate-based seed transfer practices.

Literature Cited

British Columbia Ministry of Forests, Lands, Natural Resource Operations and Rural Development. 2019. CBST Seed Selection and Deployment. Transitioning British Columbia To Climate Based Seed Transfer. Information Bulletin 5. 2 pp.

van Kerkhof, B. 2019. Development of Climate-Based Seed Transfer Policy in Ontario. Tree Seed Working Group News Bulletin, No 68, p 14

Chapter 11. Institutional framework for the conservation, use and development of forest genetic resources

11.1. National coordination mechanism on forest genetic resources, operation and structure

CONFORGEN (Conservation of Forest Genetic Resources; www.conforgen.ca) is a Canadian program consisting of forest genetics experts across the country that provides a framework for a coordinated approach to forest genetic resource (FGR) conservation. The organization aims to promote conservation, define science-based guidelines for conservation, and to monitor and identify emerging issues and research priorities for genetic resources. The Canadian Forest Service provides the secretariat. The steering committee is made up of representatives from provincial forest genetics councils, provincial and territorial governments, First Nations, and the Canadian Forest Service. Finally, a standing technical committee, consisting of provincial, federal and academic experts, oversees projects. A business plan guides CONFORGEN's activities.

The Canadian Forest Genetics Association (CFGA) is a network of forest genetics scientists and practitioners across Canada that promotes the use of scientifically and technically sound genetic practices in Canadian forestry activities (www.cfga-acgf.com). Conferences are organized every two years bringing together members for business and technical sessions around current issues regarding FGR. Since Canada's 2012 Report was published, CONFORGEN has organized and delivered several web-deployed seminars on forest genetic conservation topics, as well as fora on conservation of FGR, in conjunction with the biennial CFGA conferences. Products emerging from these meetings included conservation guidelines developed for seven tree species, a drafted scientific paper on *ex situ* conservation, and approval of guidelines for *ex situ* conservation and storage of FGR.

11.2. The main institutions and stakeholders involved in the conservation, use and development of forest genetic resources

The main institutions involved in conservation, use and development of FGR are provincial government Ministries or Departments of Natural Resources and Environment, the Canadian Forest Service, Parks Canada and universities. Stakeholders include forest industry, the energy sector and others involved in land reclamation or restoration, and urban foresters.

11.3. How different stakeholders are involved in decision-making related to FGR management

Final authority in decision-making with regard to FGR management in each province rests with the provincial department or ministry that holds responsibility for natural resources. These agencies work to varying extents with other stakeholders.

In New Brunswick, the provincial government and industry stakeholders work closely to ensure breeding plans and orchard planning. For example, they jointly use the data arising from genomics work to plan the future selective tree breeding management practices. Sharing this data represents an important step forward for stakeholders, since it saves time in establishing and implementing management actions.

In Quebec, the main stakeholder is the Government of Quebec. This agency is responsible for providing adapted seeds and seedlings to reforestation programs and for establishing rules regarding the maintenance of genetic diversity in breeding programs, seed orchards, and varieties deployed in reforestation programs. The Quebec Government is also responsible for maintaining and delimiting new *in situ* conservation areas and for species designations under the vulnerable and threatened species Act. The second important stakeholder in Quebec is the federal government (Canadian Forest Service), which maintains a research centre in Quebec with expertise in FGR and a mandate to monitor various aspects related to the health of Canadian forests, including climate change and its impacts on FGR. Forest industry is an additional important stakeholder.

In Ontario, all of the main stakeholders participate in consultation processes when developing policy or changing management directions: provincial government (Ministry of Natural Resources and Forestry and Ministry of Environment Conservation and Parks); forest industry, and; regional genetic associations. Natural Resources Canada is also involved in developing the new climate-based seed transfer rules in that province.

Alberta has provincial multi-stakeholder associations related to selective tree breeding, comprised of provincial government, industry, and academic representatives. Each of these stakeholders have a role in decision-making, while the provincial government has ultimate authority for management of FGR on Crown land and it owns and operates most of the orchards. Some forest companies also develop and fully own certain selective tree breeding programs, including orchards, trials and seed. In this capacity, the forest companies carry out operational planning related to selective tree breeding, planting of selected seedlings, and collection of operational reforestation material. Consequently, the companies can have substantial influence in decision-making. University scientists are carrying out research in collaboration with government and sometimes industry, and they also often provide significant input to decision-making.

In British Columbia, the Forest Genetics Council provides advice to the chief forester. Through the technical advisory committees there are opportunities for input from the key stakeholders, including provincial and federal government, industry, universities, seed providers, and seed users. The tree breeders move these programs forward and are ultimately in charge of the management of genetic resources for the species with which they work.

11.4. Specific policies and strategies on forest genetic resources

Each jurisdiction has its own set of policies and strategies for managing FGR. British Columbia's Forest Genetic Council has consecutive 5-year strategic plans that envision "BC's forest genetic resources are diverse, resilient, and managed to provide multiple values for the benefit of present and future generations". The goals of the current strategic plan are: (1) Conservation (maintenance of natural levels of genetic diversity for all species indigenous to British Columbia); (2) resilience (assigning appropriate seed genotypes to planted sites and maintaining natural genetic diversity in planted populations of trees); and 3) value (increasing the timber and non-timber economic value of planted forests) (https://www.fgcouncil.bc.ca/FGC_Strategic_Plan_Web_2015_20_04Nov2015.pdf). This vision extends to all native tree species in British Columbia and the scope of the strategy includes research, conventional tree breeding, seed production, pest management, decision-support, and support for new technologies.

In the provinces with the largest forest areas, policies on seed transfer have been or are being modified to move away from geographically-based seed transfer and toward climate-based seed transfer.

11.5. Specific legislation and/or regulations on forest genetic resources developed in Canada

In Alberta, standards have been developed for all aspects of forest genetic management: "Alberta Forest Genetic Resource Management and Conservation Standards." Areas covered include: policy issues (e.g., Access and Benefit Sharing) and international agreements; material collection, handling, registration and storage; Green Area (unoccupied Crown land) deployment; breeding, testing and verification, and; production of controlled parentage materials. The standards, in each of the areas are detailed, covering every step in the management of FGR (https://open.alberta.ca/publications/9781460131596).

British Columbia also has policies on selectively bred seed use and seed transfer, described in Chapters 8 and 9 of this report. Guidance on specific seed-related topics is provided by the province's Chief Forester.

11.6. Specific legislation or regulations on forest genetic resources established in Canada

Alberta's standards were enabled through Alberta's Timber Management Regulation 144.2 and were effective as of May 01, 2003.

11.7. The state of research and development on forest genetic resources

Strong research teams in Quebec, Alberta, and British Columbia involving university, provincial, and federal government scientists are producing world-recognised genetic and genomic advances in tree species of commercial and conservation value. In Quebec, collaborative studies between universities (University of Laval), researchers from the provincial government, and Natural Resources Canada (Canadian Forest Service) include evaluating genetic diversity for wood quality, and resilience traits related to abiotic and biotic stress such as drought resistance and natural resistance to insect pests. They are also studying how genetic diversity for these newly investigated traits can be integrated in the on-going tree breeding programs, and are designing quick assessment tools to evaluate FGR at the molecular/genomic levels in natural populations and in tree breeding programs. The aim of this work is to integrate assessment tools with management operations of provincial tree breeding programs and seedling production, providing a means for pedigree control and monitoring for genetic diversity of selectively bred varieties. Collaborative research efforts in British Columbia have focused on adaptive and resistance traits, particularly understanding them from an evolutionary perspective.

Tables 5.1, 5.2 and 9.1 list tree genetic and genomic studies that have been carried out since 2012. Forty-three of these studies collectively contributed to the understanding of genetic diversity across a range of native tree species. Basic genetic and genomic questions were addressed by 67 studies via analyses of organelle sequence data, gene structure, variation in gene copy number, SNP genotype arrays, genome wide phenotypic associations, and gene expression. Forty tree studies focused on selection and breeding.

11.8. The state of education and training on forest genetic resources

The main universities conducting high level FGR research and training significant numbers of graduate students are the University of British Columbia (UBC), the University of Alberta (UA), and Laval University. Other institutions that have traditionally conducted research on genetic resources are the University of Victoria and Simon Fraser University in British Columbia, Lakehead University in Ontario, and the University of New Brunswick. Relatively new active institutions that are producing graduate students in the field of tree genetics (but that lack undergraduate curricula specifically in that field) are Laurentian University, Trent University, and Carleton University (Ontario), and Concordia University (Quebec).

Table 11.1 lists some of the graduate research on FGR of indigenous tree species completed since 2012 at universities across Canada. About one-third of the theses and dissertations focus on traits or issues of direct value to selective tree breeding programs, one-third increase basic knowledge of the genetics or genomics of tree species, and many of the rest concern conservation or amelioration of impacts of soil pollution. This sample indicates that graduate students are being trained across a range of genetic resources issues that support selective tree breeding programs directly or indirectly.

Table 11.1. A sample of theses and dissertations completed since 2012 on studies of FGR of Canadian tree species.

University	Candidate name	Year	Thesis title
Laval University, Doctorate	Méndez Espinoza, C.	2018	White spruce resistance against the spruce budworm: Genetic control and insect-host interaction
Laval University, Doctorate	Lamara, M	2017	Genetic architecture of traits related to wood, growth and spruce budworm resistance in white spruce
Laval University, Doctorate	Sahli, A.	2017	Copy number variations in white spruce gene space

University	Candidate name	Year	Thesis title
Laval University, Doctorate	Sena, J.S.	2017	Structural and functional evolution of genes in conifers
Laval University Doctorate	Cinget, M.B.	2015	Pan-Canadian phylogeographic study of balsam fir (*Abies balsamea*) and its relationships with subalpine fir (*Abies lasiocarpa*) in western Canada
Laval University, Doctorate	Verta, J.P.	2014	Genetics of gene expression in conifers.
University of British Columbia, Doctorate	Ukrainetz, N.K.	2020	Patterns of genotype-environment interactions and sensitivity to genomic selection in the lodgepole pine breeding program in British Columbia
University of British Columbia, Masters	Vincent Hanlon, V.	2018	Heritable somatic mutations accumulate slowly in Sitka spruce but increase the per-generation mutation rate considerably
University of British Columbia, Doctorate	Elleouet, J.	2018	Linking demographic history and evolution at the expanding range edge of Sitka spruce (*Picea sitchensis*)
University of British Columbia, Doctorate	Ian MacLachlan	2017	Selective breeding of lodgepole pine and interior spruce generates growth gains but maintains phenotypic and genomic adaptation to climate
University of British Columbia, Doctorate	Ahmed, S.S.	2016	Impacts of tree improvement programs on yields of white spruce and hybrid spruce in the Canadian boreal forest
University of British Columbia, Doctorate	De La Torre, A.R.	2012	Genetic structure, gene flow and local adaptation in the interior spruce hybrid zone
University of British Columbia, Masters	Nadeau, S	2014	Genetic population structure and adaptation to climate across the range of eastern white pine (*Pinus strobus* L.) and western white pine (*Pinus monticola*)
University of Alberta, Masters	Sinclair, L.	2019	Drought adaptation of white spruce across the continent: physiology, phenology and field performance
University of Alberta, Doctorate	Sebastian-Azcona, J.	2018	Climate adaptation of white spruce and lodgepole pine: from phenotypes to genomes

University	Candidate name	Year	Thesis title
University of Alberta, Masters	Sekely, J.	2018	Conservation of forest genetic resources in Alberta
University of Alberta, Doctorate	Isaac-Renton, M.	2017	Growth and survival of lodgepole pine genotypes under extreme climate events
University of Alberta, Doctorate	Montwe, D.	2015	Identifying drought resistant genotypes of Douglas-fir and lodgepole pine in provenance trials through tree ring analysis
University of Alberta, Doctorate	Ding, C.	2015	Ecological and quantitative genetics of *Populus tremuloides* in western Canada.
University of Alberta, Masters	Russell, E	2014	Conservation planning for forests, tree species and their genetic populations.
University of Alberta, Masters	Liepe, K	2014	Genetic variation in lodgepole pine ad interior spruce: adaptation to climate and implications for seed transfer
University of Alberta, Doctorate	Roberts, D.R.	2013	Biogeographic histories and genetic diversity of western North American tree species: implications for climate change.
Laurentian University, Doctorate	Kalubi, K.N.	2018	Comparative molecular analyses between red maple (*Acer rubrum*) and trembling aspen (*Populus tremuloides*) exposed to soil metal contamination: metal translocation, gene expression, and DNA methylation
Laurentian University, Doctorate	Theriault, G.,	2017	Molecular analysis of *Betula papyrifera* populations from a mining reclaimed region: genetic and transcriptome characterization of metal resistant and susceptible genotypes
Laurentian University, Masters	Makela, M.	2016	Molecular analysis of northern red oak (*Quercus rubra*) populations from the Greater Sudbury Region: genetic variation and gene expression
Simon Fraser University, Masters	Zhou, C.	2018	Development of micro-propagation in bigleaf maple (*Acer macrophyllum*) and screening for early markers preceding figured wood formation
University of Victoria, Doctorate	Vance, M.	2019	Population genomics of a high-elevation conifer, subalpine larch (*Larix lyallii* Parl.)
Concordia University, Doctorate	Thomson, A.	2013	Phylogeography, introgression, and population structure of the eastern North American birches *Betula alleghaniensis*, *B. papyrifera*, and *B. lenta*

University	Candidate name	Year	Thesis title
Lakehead University, Masters	Alves, M.A.	2012	Genetic variation and adaptation of white birch populations across Canada
Carleton University, Masters	Hayes, A.D.	2019	The genetic structure of *Celtis tenuifolia* and comparisons to the related species *C. occidentalis*, and *C. laevigata*: Implications for the conservation management of threatened populations in Southern Ontario
Trent University, Masters	Lumb, S.	2018	Population genetics and scarification requirements of *Gymnocladus dioicus*

11.9. Needs, challenges and opportunities for strengthening the national (or sub-national) institutions and policies on forest genetic resources

Better visibility is needed to highlight the importance of FGR. Stronger coordination and stewardship of FGR at the national level has been suggested as potentially useful because it would allow policy to cascade to the provincial level. Building national policies has in general been difficult due to the fact that each Province owns and independently manages their tree breeding populations. This weakens federal authority on national FGR conservation ventures. Consequently, progress in this direction will entail active province-level government engagement and collaboration. CONFORGEN previously sought to build support for nation-wide FGR conservation in consultation with all treed jurisdictions. However, insufficient resources prevented that organization from establishing a national strategy and progress in this direction has waned in recent years.

Province-level limitations also exist for FGR conservation. For example, in Ontario operational selective tree breeding is no longer carried out by government and this has been accompanied by a serious loss of expertise. In particular, resource and personnel limitations hinder the development of institutions and policies for FGR. In Alberta, greater clarity is required on the roles of different agencies involved in FGR management and application of policies. Challenges include: avoiding administrative and reporting duplication; ensuring consistency across jurisdictions, and; unmanageable tasking. The main perceived opportunity to help remedy this situation is better data sharing.

11.10. Priorities for capacity-building in this area

No priorities for capacity-building have been identified specifically for this area.

Literature Cited

Ahmed, S.S., 2016. Impacts of tree improvement programs on yields of white spruce and hybrid spruce in the Canadian boreal forest. Doctoral dissertation, University of British Columbia

Alberta Government. 2016. Alberta forest genetic resource management and conservation standards. Third revision of STIA. Forestry Division, Alberta Agriculture and Forestry Edmonton, Alberta, Canada. https://open.alberta.ca/publications/9781460131596 (Accessed March 2021).

Alves, M.A., 2014. Genetic variation and adaptation of white birch populations across Canada. Master's thesis, Lakehead University, Thunder Bay, Ontario

Benomar, L., Lamhamedi, M.S., Villeneuve, I., Rainville, A., Beaulieu, J., Bousquet, J. and Margolis, H.A., 2015. Fine-scale geographic variation in photosynthetic-related traits of *Picea glauca* seedlings indicates local adaptation to climate. Tree physiology, 35(8), pp.864-878.

British Columbia Ministry of Forests, Lands, Natural Resource Operations and Rural Development. 2018. Chief Forester's Standards for Seed Use. Amendments Established April 5, 2018 with Effective Date of August 6, 2018. Victoria, BC, Canada. https://www2.gov.bc.ca/gov/content/industry/forestry/managing-our-forest-resources/treeseed/legislation-standards/chief-forester-s-standards-for-seed-use (Accessed January, 2021).

Canadian Forest Genetics Association. 2020. www.cfga-acgf.com (Accessed January 2021)

Chamberland, V., Robichaud, F., Perron, M., Gélinas, N., Bousquet, J. and Beaulieu, J., 2020. Conventional versus genomic selection for white spruce improvement: a comparison of costs and benefits of plantations on Quebec public lands. Tree Genetics & Genomes, 16(1), pp.1-16.

Cinget, B., 2015. Étude phylogéographique pancanadienne du sapin baumier (*Abies balsamea* [L.] Mill.) et de ses relations avec le sapin subalpin (*Abies lasiocarpa* [Hook] Nutt.) dans l'ouest du Canada. Doctoral dissertation, Laval, Quebec

De La Torre Cuba, A.R., 2012. Genetic structure, gene flow and local adaptation in the interior spruce hybrid zone. Doctoral dissertation, University of British Columbia

De La Torre, A.R., Wang, T., Jaquish, B. and Aitken, S.N., 2014. Adaptation and exogenous selection in a *Picea glauca* × *Picea engelmannii* hybrid zone: implications for forest management under climate change. New Phytologist, 201(2), pp.687-699.

Ding, C. 2015. Ecological and quantitative genetics of *Populus tremuloides* in western Canada. Doctoral dissertation, University of Alberta

Elleouet, J.S., 2018. Linking demographic history and evolution at the expanding range edge of Sitka spruce (*Picea sitchensis*). Doctoral dissertation, University of British Columbia

FGC. (2015). Forest Genetic Council of British Columbia: Strategic Plan 2015-2020. Victoria, 816
BC. https://forestgeneticsbc.ca/wp-content/uploads/bsk-pdf-manager/2020/07/FGC_Strategic_Plan_Web_2015-20_04Nov2015.pdf (Accessed March 2021)

Hanlon, V.C.T., 2018. Heritable somatic mutations accumulate slowly in Sitka spruce but increase the per-generation mutation rate considerably. Master's thesis, University of British Columbia.

Hayes, A.D., 2019. The genetic structure of *Celtis tenuifolia* and comparisons to the related species *C. occidentalis*, and *C. laevigata*: Implications for the conservation management of threatened populations in Southern Ontario. Master's thesis, Carleton University, Ottawa, Ontario

Isaac-Renton, M. 2017. Growth and survival of lodgepole pine genotypes under extreme climate events. Doctoral dissertation, University of Alberta

Kalubi, K.N., 2018. Comparative molecular analyses between red maple (*Acer rubrum*) and trembling aspen (*Populus tremuloides*) exposed to soil metal contamination: metal translocation, gene expression, and DNA methylation. Doctoral dissertation, Laurentian University of Sudbury, Ontario

Lamara, M. 2017. Genetic architecture of traits related to wood, growth and spruce budworm resistance in white spruce. Doctoral dissertation, Laval University, Quebec

Liepe, K. 2014. Genetic variation in lodgepole pine and interior spruce: adaptation to climate and implications for seed transfer. Master's thesis, University of Alberta

Lumb, S. 2018. Population genetics and scarification requirements of *Gymnocladus dioicus*. Master's thesis, Trent University, Peterborough, Ontario

MacLachlan, I.R., 2017. Selective breeding of lodgepole pine and interior spruce generates growth gains but maintains phenotypic and genomic adaptation to climate. Doctoral dissertation, University of British Columbia

Makela, M., 2016. Molecular analysis of northern red oak (*Quercus rubra*) populations from the Greater Sudbury Region: genetic variation and gene expression. Master's thesis, Laurentian University of Sudbury, Ontario

Méndez Espinoza, C., 2018. White spruce resistance against the spruce budworm: Genetic control and insect-host interaction. Doctoral dissertation. Laval University, Quebec

Montwe, D. 2015. Identifying drought resistant genotypes of Douglas-fir and lodgepole pine in provenance trials through tree ring analysis. Doctoral dissertation, University of Alberta

Nadeau, S., 2014. Genetic population structure and adaptation to climate across the range of eastern white pine (*Pinus strobus* L.) and western white pine (*Pinus monticola* Douglas ex D. Don). Master's thesis, University of British Columbia

Natural Resources Canada. 2017. CONFORGEN: Conservation of forest genetic resources in Canada. www.CONFORGEN.ca (Accessed January, 2021)

Ontario Ministry of Natural Resources and Forestry. 2020. Ontario Tree Seed Transfer Policy. https://www.ontario.ca/page/ontario-tree-seed-transfer-policy (Accessed January 2021)

Province of Alberta. 2020. Forests Act: Timber Management Regulation. Alberta Regulation 60/1973 with amendments up to and including Alberta Regulation 236/2020; Current as of November 25, 2020. https://www.qp.alberta.ca/documents/Regs/1973_060.pdf (Accessed January 2021)

Roberts, D.R. 2013. Biogeographic histories and genetic diversity of western North American tree species: implications for climate change. Doctoral dissertation, University of Alberta

Russell, E. 2014. Conservation planning for forests, tree species and their genetic populations. Master's thesis, University of Alberta

Sahli, A., 2017. Copy number variations in the gene space of *Picea glauca*. Doctoral dissertation. Laval University. Quebec

Sebastian Azcona, J., 2019. Adaptation of white spruce populations to extreme climate events: implications for assisted migration practices in Western Canada. Doctoral dissertation, University of Alberta

Sekely, J. 2018. Conservation of forest genetic resources in Alberta. Master's thesis, University of Alberta

Sinclair, L. 2019. Drought adaptation of white spruce across the continent: physiology, phenology and field performance. Master's thesis, University of Alberta

Stival Sena, J., 2017. Structural and functional evolution of genes in conifers. Doctoral dissertation, Laval University, Quebec

Theriault, G., 2017. Molecular analysis of Betula papyrifera populations from a mining reclaimed region: genetic and transcriptome characterization of metal resistant and susceptible genotypes. Doctoral dissertation, Laurentian University of Sudbury, Ontario

Thomson, A., 2013. Phylogeography, introgression, and population structure of the eastern North American birches *Betula alleghaniensis*, *B. papyrifera*, and *B. lenta*. Doctoral dissertation, Concordia University, Montreal, Quebec

Ukrainetz, N.K., 2020. Patterns of genotype-environment interactions and sensitivity to genomic selection in the lodgepole pine breeding program in British Columbia. Doctoral dissertation, University of British Columbia

Vance, M., 2019. Population genomics of a timberline conifer, subalpine larch (*Larix lyallii* Parl.). Doctoral dissertation, University of Victoria, British Columbia

Verta, Jukka-Pekka. 2014. Genetics of gene expression in conifers. Doctoral dissertation. Laval University, Quebec

Zhou, C., 2018. Development of micro-propagation in bigleaf maple (*Acer macrophyllum*) and screening for early markers preceding figured wood formation. Master's thesis, Science: Biological Sciences Department, Simon Fraser University, British Columbia

Chapter 12: International and regional cooperation

12.1. International and regional projects on forest genetic resources of which Canada has been, or is, involved since 2013

Canadian forest geneticists have collaborated with international research partners in numerous projects since 2013, strongly advancing our ability to effectively manage Canada's forest genetic resources (FGR). Sally Aitken, at the Conservation Genetics Centre at the University of British Columbia, for example, worked with eminent European scientists and co-authored a seminal paper in a commemorative bookmarking the 10-year anniversary of the European research program, EVOLTREE (Alberto *et al*., 2016). Funding from the Canadian initiative called AdapTree made the collaboration with European scientists in this context possible. In a second example, El-Kassaby and his group at the University of British Columbia collaborated on numerous projects with research partners in China (see, for example, Sun *et al.* 2020a), and Europe (Lstiburek *et al.* 2020b) to build on basic genetic and genomic knowledge of forest trees for application to selective breeding. Collaborative research also continues on genetics and genomics of *Populus* spp across the United States/Canada border, as well as with researchers in China and other countries (see, for example, McKown *et al*., 2017). Finally, the tree genetics and genomics research group in Quebec collaborates with scientists in other regions of Canada as well as other countries (e.g., Isabel *et al.,* 2019).

The North American Forest Commission's Forest Genetic Resource Working Group, operating under the auspices of the Food and Agriculture Organization of the United Nations, is an example of a regional network that continues to be beneficial for Canada (Table 12.1). Since its formation in 1961, the working group has addressed multiple forest genetic resources (FGR) research questions collaboratively between the United States, Mexico and Canada. It focuses on conservation genetics research (mostly in Mexico) and raising awareness of sustainable management of FGR while taking into account climate change, using training sessions, conferences, publications, model scenarios and seed-source or migration guidelines (North America Forest Commission 2017). The Working Group delivers high quality science and science-to-policy tools to support sustainable forest management and conservation of FGR, while also linking with national forest management agencies and contributing to the FAO's FGR Global Plan of Action.

12.2. How Canada has benefitted from the international and regional cooperation on forest genetic resources

The primary benefit to Canada of international collaborative research is realised through research breakthroughs and information exchange that lead to new approaches and tools to address tree genetic challenges faced in Canada. There are numerous programs touching on FGR that have benefited Canada, either by promoting research efforts, enhancing collaboration, technology, and data exchange, or clarifying some of the issues pertaining to Indigenous peoples' claims that may include forested areas. Examples described in the 2012 Canadian FGR country report include: the Circumboreal Vegetation Mapping Initiative; the International Union of Forestry Organizations (IUFRO); the Millennium Seed Bank Project, and; the Taiga Rescue Network.

12.3. Contributions provided to the international and regional cooperation on forest genetic resources

Canada provides significant contributions cooperation on FGR, by sharing research capacity and expertise and by providing training. The most direct Canadian contributions have been through the North American Forestry Commission's Working Group on Forest Genetic Resources (NAFGRWG).

12.4. Application of the results and/or benefits from the international and regional cooperation for the conservation, use and development of forest genetic resources in Canada

Collaboration in international genomic research on adaptation to climate change is applicable to the same questions in Canada.

12.5. Needs, challenges and opportunities for strengthening the international and regional cooperation on forest genetic resources

The level of international collaboration in Canada for FGR appears to have decreased over the past eight years, possibly because of reduced research budgets that restrict travel or scientific exchange at the level required to develop strong collaborations. Importantly, the distribution of genetic diversity in nature, and forces strongly shaping that diversity or its adaptive potential (e.g., climate change, invasive species, forest pests and diseases), spans political borders, and so management of FGR entails nation-wide and regional cooperation.

Canada presently has numerous partnerships with the United States and Mexico (e.g., the North American Forest Commission of the Food and Agriculture Organization). As noted in Canada's 2012 FGR Report, collaboration to amalgamate knowledge and data pertaining to FGR that are hosted by various agencies and institutions in all three countries would be very beneficial, enhancing continent-wide conservation and management strategies. The sharing of national forest resource inventories across Canada, the United States, and Mexico could include forest ecosystem maps and disturbance databases. The opportunity to further strengthen relationships and cross-border studies will become more apparent as knowledge of FGR accrues.

Monitoring, which can be closely linked to information management, is also important for understanding and recognizing the importance of FGR. Monitoring can be of FGR directly, as well as of biotic (e.g., invasive alien species) or abiotic stressors (e.g., climate) impacting these resources at a regional level (i.e., North America). Work of this type is highly beneficial for developing effective long-term strategies for conserving FGR and for either minimizing the impacts of the stressors above or for developing scale-appropriate mitigation strategies. Concerning invasive alien pests that can impact the forest sector, the sharing of data concerning outbreaks in other regions (e.g., European and Asian forests) is also important as this can assist Canadian researchers and forest managers in developing proactive responses to future potential stresses.

Further networking to maintain the existing research capacity and to expand upon it is also useful. Continued collaborative research, such as that which is ongoing through the North American Forest Commission's Working Groups (WG), is important as it addresses issues that are often addressed at the level of species distribution within North America. It is also important to enhance the ability of research to inform policy at national and regional levels, and to coordinate its implementation.

Priorities for future international collaborations include documenting the species-specific magnitude and geographic distribution of FGR in nature, enhancing education about the importance of FGR, improving FGR information management, and establishing early warning systems for FGR. Near-term priorities in Canada toward these goals include enhancing in situ and ex situ management and conservation, enhancing the use of FGR, expanding research on FGR, legislating FGR conservation, and public awareness campaigns.

Literature Cited

Alberto, F.J., Aitken, S.N. Alia, R., Gonzalez-Martinez, S.C., Hanninen, H., et a. 2016. Potential for evolutionary responses to climate change – Evidence from tree populations. Evolution of Trees and forest communities. PG Edition, 175 p.

Isabel, N., Holliday, J.A. and Aitken, S.N., 2020. Forest genomics: Advancing climate adaptation, forest health, productivity, and conservation. Evolutionary Applications, 13(1), pp.3-10.

Jia, K.H., Zhao, W., Maier, P.A., Hu, X.G., Jin, Y., Zhou, S.S., Jiao, S.Q., El-Kassaby, Y.A., Wang, T., Wang, X.R. and Mao, J.F., 2020a. Landscape genomics predicts climate change-related genetic offset for the widespread *Platycladus orientalis* (Cupressaceae). Evolutionary applications, 13(4), pp.665-676.

Lstiburek, M., Schueler, S., El-Kassaby, Y.A., Hodge, G.R., Stejskal, J., Korecky, J., Skorpik, P., Konrad, H. and Geburek, T. 2020b. In Situ Genetic Evaluation of European Larch Across Climatic Regions Using Marker-Based Pedigree Reconstruction. Frontiers in Genetics 11:28

McKown, A.D., Klápště, J., Guy, R.D., Soolanayakanahally, R.Y., La Mantia, J., Porth, I., Skyba, O., Unda, F., Douglas, C.J., El-Kassaby, Y.A. and Hamelin, R.C., 2017. Sexual homomorphism in dioecious trees: extensive tests fail to detect sexual dimorphism in Populus. Scientific reports, 7(1), pp.1-14.

Chapter 13. Recommended actions for the future

13.1 Availability of information on forest genetic resources

Canada has made strong advances in generating knowledge of genetic resources and genomics of commercially important native tree species. Great advances have been made in understanding patterns of diversity in adaptive traits and in the genetic basic for traits related to productivity. The impacts of climate change are felt now across the country and several jurisdictions are changing seed transfer approaches. Significant gaps remain however, both in terms of scientific knowledge and in sharing knowledge with policy makers and public.

Research needs:

1) basic genetic and genomic knowledge on species that have not traditionally been used in reforestation programs to meet the need for restoration and land reclamation planting material;
2) impacts of climate change and seed transfer rules for conducting restoration efforts;
3) seed supply and demand for restoration and reclamation;
4) understanding evolutionarily adaptive response to climate change, including testing tree genotypes grown under past climatic conditions for suitability to new climatic environments;
5) mechanisms and distribution of insect and disease tolerance or resistance;
6) understanding the genetic basis and patterns of diversity in wood properties, and;
7) improving the practicality of use of genomics technologies.

Outreach and information sharing needs:

1) development of targeted communications strategies that are specific to forest genetic resources (FGR);
2) promoting increased awareness of the importance of FGR in forest resource management. This needs to be incorporated in forest management courses at college and university levels (e.g., as is currently occurring in Quebec).

13.2 Conservation of forest genetic resources

Identified needs:

1) increased financial support for assessment of *in situ* FGR for all tree species in Canada, in order to provide a foundation of data for: prioritizing tree populations for *in situ* and *ex situ* conservation, establishing baseline species-specific genetic diversity measures against which to evaluate the success and evolving needs of FGR conservation in light of changing environmental pressures or forestry applications, and exploring potentially adaptive genetic variation relevant to environmental pressures or forestry applications;

2) increased financial support for *ex situ* conservation of genetic resources, both through expanded traditional and non-traditional storage capacity for tree germplasm and by maintaining field gene banks and provenance and progeny trials;
3) centralized data storage such as tree seed databases integrated between jurisdictions, and also internationally, for species requiring conservation;
4) increased capacity for research and expertise in seed storage behavior;
5) creating awareness of the long-term cost associated with taking no action compared with the cost of conservation;
6) development of a national long-term seed and germplasm conservation strategy;
7) inventorying and monitoring FGR: necessary for development and implementation of plans and strategies for use and conservation, particularly regarding less studied species, and;
8) prioritizing species listed as endangered or threatened for conservation of populations throughout the native range.

13.3 Use, development and management of forest genetic resources

The biggest issue facing tree breeders and forest managers is dealing with climate change impacts. Developing and deploying new climate-based seed transfer approaches for seedlot selection and deployment is introducing new challenges. Industry may not be willing or able to accept the additional complexities, so provincial forest ministries must be prepared to provide the necessary support.

Identified needs:

1) building a stronger forest health component into breeding programs to take full advantage of advanced generation breeding material;
2) enhancing selective tree breeding programs for promising species both for commercial forestry and restoration/reclamation;
3) developing methodology to streamline or optimize breeding for multiple traits and diversifying end product mix while addressing all potential client interests with existing programs; for example, resolving the challenge of increasing gain in productivity without detrimentally affecting genetic gain in adaptation;
4) developing FGR inventories, in particular identifying tree genetic resources related to adaptation and resilience, for use by forest managers;
5) including insect and disease susceptibility and resilience in predictive modelling;
6) developing rapid assessment methods such as genetic markers to identify valuable genetic resources quickly in a large number of species. This includes rare and abundant species, angiosperms as well as gymnosperms, to increase agility of forest management under changing climates;
7) accessing seed from tree and shrub species that are not currently used for artificial regeneration in a commercial forestry context, and;

8) increasing capacity for running selective tree breeding programs at the jurisdictional level. This is particularly important as provinces move to climate-based seed transfer approaches while second and third-generation seed orchards are in development. Expanded capacity for establishing, testing and maintaining advanced generation seed orchards is required as well as highly qualified personnel to carry out the modelling, field testing, and collection and deployment planning under new climate-based seed transfer rules. The required capacity ranges from establishing, documenting and maintaining field trials, such as realised gain trials, to development and application of genomic selection tools.

13.4 Policies, institutions and capacity-building

Government at provincial and federal levels needs to take a stronger position and increase its role in selective tree breeding. Increasing impacts of fire, insect pests, and disease coupled with long rotations, FGR management is less attractive as an investment than it used to be, which diminishes incentives to industry for selective tree breeding.

There is a general need for greater leadership and more engagement of personnel at provincial and federal levels to build awareness of the importance of FGR among the general population and decision-makers. Despite the inherent barriers in policy and methodological transfer between provinces, or between provinces and the federal governments, stronger coordination and stewardship of FGR at the national level has been mentioned as potentially useful due to its potential to cascade to the provincial level.

Efforts towards strengthening Canada's national institutions and policies with regard to FGR have been waning in recent years. Until 2017, CONFORGEN sought to build support nationally, drawing in all of the treed jurisdictions and worked to build support for conservation strategies for FGR. However, insufficient resources, combined with the complications of harmonizing approaches across provinces as noted above, meant that CONFORGEN members were not able to continue developing national strategies.

All jurisdictions are in early stages of climate-based seed transfer approaches. Additional capacity-building is needed to fully appreciate the complexities introduced with these approaches and to ensure their appropriate application.

Needs with respect to policies and institutions:

1) stable funding. Year-to-year funding does not allow for the long-term view that is needed for proper development and maintenance of FGR programs;
2) balancing economic development with stewardship mandates is a challenge in each jurisdiction;
3) increasing collaboration. Research collaboration between government and universities has increased in some jurisdictions, but more interaction would be productive, as well as greater collaboration between government departments and between provinces;

4) increasing the number of qualified personnel with forest genetics and forest insect and disease expertise;
5) supporting adequate nursery space and tree planters, both of which may be limiting factors in planting programs;
6) increasing scientific support at multiple levels and locations, along with increased funding, for example from Genome Canada, to understand tree genetic resources, as a value in their own right rather than a by-product of tree breeding or other research endeavour;
7) increasing clarity on the roles of different agencies involved in FGR management and application of policies. Challenges include: avoiding administrative and reporting duplication, ensuring consistency across jurisdictions, and unmanageable tasking, and;
8) strengthening and supporting CONFORGEN

Needs with respect to capacity building:

1) capacity at provincial government level is low in most jurisdictions as a result of retirements and funding cuts; rebuilding lost capacity is vital;
2) increasing capacity to handle tree breeding complexities accompanying efforts to implement climate-based seed transfer approaches while also capitalizing on existing advanced generation seed orchards that were originally constituted for specific zones and multiple trait selection with increasing emphasis on adaptive traits;
3) developing highly qualified technical and research staff to address adaptation to climate change, breeding for multiple traits including those important in resiliency, and expanding knowledge of species with low economic value or of lower priority in reforestation programs, and;
4) increasing capacity for data management is increasingly complex with the breeding and selection complexities mentioned above, particularly as marker-assisted and genomic selection use increases.