Tomorrow's Forests:
Tree Seed Management in Ontario

Forest Gene Conservation Association

Forests Ontario

Preface

This paper summarizes much of the accumulated knowledge related to tree seed acquisition, seed management, identifies some of the species-specific complexities, and reviews program management strategies undertaken in Ontario and in other jurisdictions. It also attempts to forecast what will be required in the future to address universal opportunities and challenges posed by changes to climate, loss in biodiversity, species at risk, invasive species, and landscape sustainability, all from a tree seed perspective.

This information is intended to inform managers and organizations charged with maintaining and enhancing forest cover, and conducting tree seed management activities. Continued delivery of a robust seed management program will require focus on sound science, collaboration and long-term planning for the entire reforestation cycle.

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Contents

1.0

Executive Summary

All life on earth is reliant on trees and forests. These are dependent on a healthy, diverse and adaptable supply of tree seed. Tree seed, by its nature, is a remarkably efficient means of preserving genetic resources for future use, particularly for species with irregular crop cycles such as trees. Seed is of greatest utility to both research and practitioners when information about its source and genetic parentage is known and maintained through the regeneration process. In Ontario, it is vital to increase the supply of locally-adapted seed of native woody species. Such a supply is essential to support our forest restoration efforts, whether it is one tree in an urban back yard or tens of millions of trees to help restore a rural watershed.

However, the threat of climate change fundamentally alters the way our forests will be managed and regenerated. Thus, an adequate supply of source-identified seed collected and stored now in order to prepare for the unpredictable rapid changes to our climate is fundamental to ensuring researchers and restoration practitioners have adaptive management options now and in the future. Significant investments have been made in national and provincial seed facilities across Canada to increase the quality and quantity of seed available to Crown and private land planting programs. This includes the Ontario Tree Seed Plant and associated seed bank (in operation since 1923), the seed forecasting and collection certification program administered by Forests Ontario and Forest Gene Conservation Association, the nurseries and the more than 900 seed collectors who have been trained over the years for collection across the province.

Provincial facilities were established to forecast, coordinate, process and monitor the volume and quality of seed and stock required to regenerate large areas of managed forests under provincial policy. This allows the facilities to be well positioned to meet the climate change risks that forest scientists expect by the end of the century. Seed-related capacity in Ontario's private sector currently focuses on commercially important tree species or least problematic ornamental species with minimal long-term seed storage facilities. Coordinating, collecting and processing seed is capital and expertise-intensive and offers low economic returns compared to stock, with seed ranging from 0.3–6% of a bareroot seedling's value. However, without high quality seed, options are limited to pass on improved or best-adapted genetic qualities to future forests.

This paper consolidates key aspects of the science and policy pertaining to seed management and relates seed management to the attainment of long-term ecological and economic goals. Beyond encouraging economic opportunities in seed management, the goal is to ensure that the long-term mandate of promoting and protecting biodiversity, mitigating climate change impacts, managing species at risk, etc., is measurable and achievable. Delivering on this mandate includes methods to:

1. Understand the conservation and population status of Ontario's native woody plant species for seed production, including forest health threats from invasive and native pests, disease and extreme weather events
2. Ensure a continuous supply of genetically appropriate seed for Ontario (annual, 10-year and long-term supply)
3. Ensure a continuous supply of genetically appropriate seed so forest managers responsible for Crown, municipal and private land can react and adapt to climate change in Ontario
4. Assess and ensure the continuity of standards and services established by the Ontario Tree Seed Plant
5. Ensure the chain of custody system for source-identified seed in Ontario continues to improve and meet new policy and climate change threats
6. Strengthen collaboration and communication with government, forest scientists, industry partners and stakeholders.

1.0

The Need for Seed

1.1 Forest Management Begins with Genetically Appropriate Seed

Seed are transmitted to a landscape naturally or artificially. Natural regeneration through sexual regeneration mechanisms requires a viable population of healthy seed producing parent trees and an available and adequate seedbed on which germination can occur. Genetic characteristics of the new cohort are entirely dependent on the quality, number and relatedness of the parent stand.

and formalized in the *Tree Improvement Master Plan for Ontario* (MNR(F) 1987) which in addition provides evidence of past seed source control/provenance testing for adaption in seed transfer.

"Tree improvement strategies differ in the way sources of variation are exploited. Local seed is usually a safe source, but provenance trials may reveal fast growing and more broadly adaptable sources. The main function of provenance trials has been to provide data for the delineation of seed zones. Seed production is then from orchards of improved, selected plus trees (for each zone).

"Provenance trials are a special type of plantation experiment that helps us understand how trees are adapted to different environmental conditions through genetic adaptation or phenotypic plasticity. Provenance means "origin" and refers to a population of trees that come from a particular location."

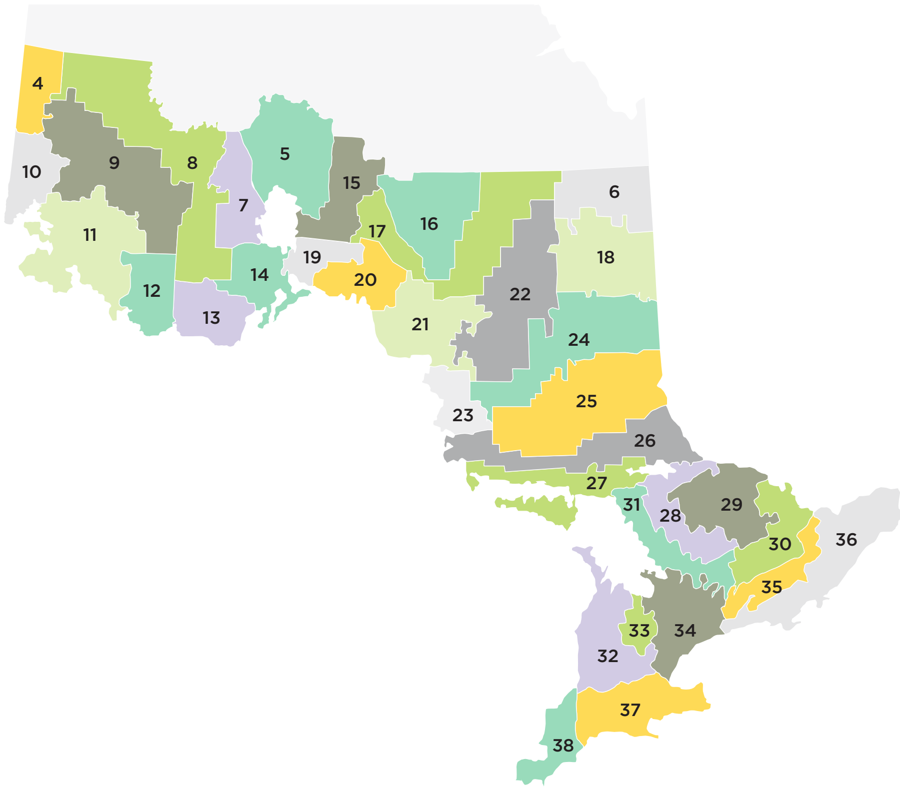
Artificial regeneration is needed when natural regeneration is deemed inadequate, in fragmented landscapes where suitable parent stands are too distant or when unrelated seedlings or faster growing seed sources of the same species or mix of different species are desired to enhance forest health and diversity values. Seeds of some forest species can be artificially sown by helicopter or other broadcasting equipment; however, tree seeds are more efficiently utilized when grown in a nursery production environment. Seedlings are planted when they are more capable of surviving.

When regenerating forests artificially, desirable traits can be selected for use. Since the mid-1950s, foresters have understood that genetic traits in trees can be selected for and bred, as with agricultural crops, to increase growth rates or disease tolerance, a process called tree improvement. In the interest of public and private land planting programs, Ontario invested in tree selection and tree improvement programs beginning in the late 1970s, notably with Black spruce, Jack pine, White spruce and White pine. These programs were further supported

The array of wild and orchard seed sources currently utilized makes proper seed source identity essential. Where seed transactions occur between agencies, identity may require certification." (Huber 1981).

Data from large scale provenance trials, as well as the Ontario Climate Model, were used to delineate Ontario's Seed Zone Map (Figure 1) as part of the seed transfer guidelines. "When seed/stock are moved some distance from their geographic origin, it is probable that they will be poorly adapted to the local climatic conditions and will be at some increased risk of damage and death due to cold, drought, insects and disease." (MNR(F) 2010). The guidelines are currently made available as part of the *Forest Operations and Silviculture Manual* (MNRF 2017a) Associated Policies.

Figure 1: Ontario Tree Seed Zones. MNR(F) (2010c). Seed zones created March 1996, from the Ontario Climate Model



For forestry species not included in tree improvement programs, fixed administrative zones and transfer rules made it easier for operational staff to track seed collection and deployment and ensure forest health and productivity was sustained. Seed is identified by the collection zone number, and a database system tracks seedlots by species, source and owner. If seed from the local zone was not available, the best second choice is seed from a site with environmental factors comparable to those at the planned planting site. Software compares climatic factors such as length of growing season, maximum and minimum seasonal temperatures, and precipitation. This ensures the genetically adapted growth processes associated with the seed source's seasonal and latitudinal patterns would be best suited to the planting site, thus reducing risk when selecting planting stock.

Climate change is expected to add high risk to future forest plantation success using local or improved seed sources. Uncertainties related to the rate and degree of impact of climate change, the need to further diversify by species and seed sources for regeneration programs in order to address those uncertainties, incomplete science related to seed storage techniques and nursery cultural practices for species with less commercial value, that up to now have not been a significant component of artificial regeneration efforts (for example Tulip tree, Hackberry, or several other Carolinian species), all point to an urgently required collection and tracking system for genetically adapted stock.

Seedlots are a particular batch of seeds, often collected from a specific area or location (e.g. Ontario tree seed zone).

1.2 Afforestation and Reforestation

Afforestation is a land reclamation process to restore forest to areas that have not been forested for many years, and in Ontario this typically refers to restoration work on lands cleared in the past for agricultural purposes. Reforestation is carried out both in Crown forests and private land soon after harvest or clearing. On Crown land, harvesting is completed according to requirements of a Forest Management Plan (key elements of the reforestation process are outlined in Figure 2).

The decline in forest cover is evident in both rural and urban private landscapes in Ontario. Harvesting on private or municipal land in Ontario should follow municipal tree cutting by-laws (if present). The success of such programs depends on many factors, often several partners working together and all with knowledge of the biological constraints around seed and stock production.

Figure 2: Reforestation Process

1.3 Tree Seed Management

Seed is crucial to all forest restoration processes. To ensure continuous and stable seedling production for projected planting programs (regardless of ownership), species demands, production targets and known supply of seed in inventory must be available in a consolidated manner to achieve long term provincial objectives. As opportunities and constraints are quantified or assessed, operational staff and contractors can undertake the following seed procurement actions (outlined in Appendix A) to acquire high quality, source-identified seed, and to provide assurance that Forest Genetic Resource Management (FGRM) standards are met (see Figure 3 for a summary of seed management program components, supports and potential constraints).

Figure 3: Seed management program, components, supports, and constraints

CRITICAL SEED PROGRAMS AND COMPONENTS		DECISIONS BASED ON
Seed and Stock Demand & Forecasting Production	WHAT SPECIES?	Forest Management Plan (FMP) objectives, site conditions, market demands
	CONSOLIDATE DEMAND X SOURCE CALCULATE SEED TARGETS	Viable seed/hl., Seed use ratios
Seed Production Areas (SPAs)	SEED ORCHARDS	Genetic worth affects decision to establish SO. Forecasted yield affects area, investment level
	HIGH QUALITY STANDS (SCAN)	Effective population size (breeding population large enough not to lose heterozygosity at a greater than normal rate)
Seed Collection	FORECASTING & COLLECTION	Trained crop forecasters and collectors available
	SHIPPING & RECEIVING	Accurate quantities
Extraction, Testing & Storage	EXTRACTION & CLEANING SEED	Quality and source identifications standards maintained through the process
	VIABILITY TESTING & STORAGE	Consistent with standards set by International Seed Testing Association (ISTA) / Association of Official Seed Analysts (AOSA) / National Tree Seed Centre (NTSC)
Seed Requistion & Inventory Mangement	SEED REQUISITION	Online requests, seed available in storage sufficient to meet demand
	INVENTORY MANAGEMENT	Central inventory established, private accounts for individual clients and seedlots maintained
Seed/FGRM Reporting, Analysis & Review	PROGRAM & POLICY REPORTING	FMP data needs; Ontario Government needs
	DATA ANALYSIS FOR GAPS & SEED RESEARCH NEEDS	Ongoing improvements in viability, seed quality and inventory

INFLUENCED AND SUPPORTED BY	POTENTIAL CONSTRAINTS
Site quality, crown health, management regime	Existing inventory (seed viability)
State of research — seed storage protocols, stock production success, conservation priority	Plans updated, loss of Seed Orchards or Seed Production Areas
Enhanced efficiency using a single inventory system	New seed orchards established when needed
Stands mapped, accessible, permission to collect seed granted by owner	Forest health, age
Targets allocated, and achieved	Limited collectors, crop failures due to weather events, insect infestation etc.
Correct seed source identification provided with each shipment	Low quality seed, proper storage and shipping protocals not followed
Expertise related to species, staff skills upgrading	Distance from collection site to processing/storage location, cost of service
Maintenance of Moisture Content (MC) or Equilibriated Relative Humidity (eRH)%; suitable lon-term storage facilities in place	Cost of service, retest frequency
Handling standards set and complied with, shipments arranged promptly, received by buyers on time	Inventory updated after requisition completed
Quadratic Residue Code (QR) / Barcode for source identification tracking	Poor quality seed — low viability or germinative energy
Source identification known for Free to Grow plots	Forest genetic resource management standards developed, understood and complied with throughout supply chain
Climate change, conservation objectives, alignment with Seed Transfer Policy	

2.0

The Role of Seed in Policy

2.1 Ontario's Forest Management Policy

Ontario's Crown forests are managed under two key pieces of legislation; the *Crown Forest Sustainability Act* (CFSA) and the *Environmental Assessment Act* (EA) with accountability for the provincial mandate assigned to the Ontario Ministry of Natural Resources and Forestry (MNRF). An articulation of the MNRF's objectives in managing the province's natural resources on a sustainable basis is available in a Statement of Environmental Values (SEV), prescribed under the *Environmental Bill of Rights*. A network of Sustainable Forest License (SFL) holders carry out forest management on Crown land in the province. SFLs are granted the authority to harvest forests in the licensed area. They are responsible for preparing forest management plans, gathering forest inventory information for the Crown, conducting operations by approved plans and standards including management of harvest and renewal, compliance monitoring and reporting. Sustainable Forest License holders are guided by the

- *Forest Management Planning Manual* (OMNRF 2017b)
- *Forest Operations and Silviculture Manual* (OMNRF 2017a)
- *Forest Information Manual* (OMNRF 2017c)
- *Forest Management Guide to Silviculture in the Great Lakes-St. Lawrence and Boreal Forests of Ontario* (OMNRF 2015)
- *Forest Management Guide for Conserving Biodiversity at the Stand and Site Scales* (2010a)
- *Forest Management Guide for Great Lakes-St. Lawrence Landscapes (2010b).*

Third-party forest management certification through organizations such as the Canadian Standards Association (CSA), Sustainable Forestry Initiative (SFI) and Forest Stewardship Council (FSC) complement Ontario's comprehensive forest management laws and regulations by providing added assurance that a forest company is operating legally, sustainably and in compliance with world-recognized standards for sustainable forest management.

Naturally Resilient: MNRF's Natural Resource Adaptation Strategy (2017–2021) (MNRF 2017d) identifies additional changes and considerations in Ontario's forest policy that are in progress: "As climate conditions shift and the types of trees that will do best in a given location change, Ontario's forest managers will be challenged to ensure they are planting trees that suit local growing conditions and continue to deliver the social, economic and ecological benefits of sustainable forest management."

2.2 Benchmarks: Forest Seed Management in Other Jurisdictions

In order to sustain Ontario's internationally-recognized forest restoration efforts, the authors of this paper undertook a review of other jurisdictions and their tree seed management efforts. These efforts may help guide Ontario's future seed management plans.

CANADIAN PROVINCES

Like Ontario, British Columbia, Quebec and Alberta depend heavily on sustainably managed forests for employment, revenue and a host of other social and environmental benefits. All three have identified strong seed management programs as critical to the success of their restoration programs, although some differences in priorities or approach are noted. Alberta and British Columbia have similar standards, in that all seed and stock deployed on public land must follow provincially-set genetic and seed handling policies and in addition, improved seed must be used when available. In British Columbia, the standards as outlined in the *Chief Forester's Standards for Seed Use* (Government of BC 2010) specify:

- That seedlots and vegetative lots must be registered and stored by the provincial Tree Seed Centre
- The type of seed source records that must be retained

- Seed purity and moisture content standards
- Rules related to collections (geographic distribution, degree of clustering, number of donor plants, to ensure genetic diversity of donor plants)
- Handling of seed before and during processing
- Seed testing standards
- Seed storage conditions.

Both provinces recognize the importance of seed processing facilities (British Columbia's program is deemed "Mission Critical" to respond to natural disturbances such as wildfire and forest pests, and with many activities within the Tree Seed Centre classified as public stewardship functions, including seed testing and storage). The provincially-run Alberta Tree Improvement & Seed Centre (ATISC) is the only facility in that province involved in testing and storage, although other facilities are able to participate if they follow the same guidelines. (However, privatization of the processing facilities in the mid-90s, testing and storage undertaken—following provincial standards—has not been profitable for private sector enterprises.)

Quebec's system is fully integrated, with the province growing reforestation stock in provincial nurseries, and while there is no specific policy in place that specifies seed must be processed, tested and/or stored at the Berthier Tree Seed Centre, the Centre has a central position. The Centre's quality policy statement states that: "By continuously improving its procedures, the Berthier Tree Seed Centre intends to actively contribute to the Ministry of Natural Resources' strategy of sustainable forest management, notably to increasing forest yields, by ensuring the production of quality seeds and meeting the expressed needs of customers at the lowest cost." (Bettez and Colas 2013).

UNITED STATES OF AMERICA

The United States Department of Agriculture's (USDA) Forest Service established a national *Native Plant Materials Policy* (FSM 2070) in 2008 which recognized "the need to maintain native plant communities as part of fully functioning ecosystems and promoted the use of native plants in revegetation projects on National Forest System lands". The policy was designed to "help combat invasive species, mitigate impacts of climate change, and maintain healthy forests." It also led to an expansion in the role of Forest Service nurseries and seed extractories from being "leaders in growing native tree seedlings for reforestation to the production of native shrubs, grasses, and wildflowers".

This policy was further supported by the *National Seed Strategy for Rehabilitation and Restoration, 2015–2020* which "provides a framework for actively working with the private sector to build a 'seed industry' for rehabilitation and restoration". One of its' key objectives is to "increase the supply and reliable availability of genetically appropriate seed".

EUROPEAN UNION

Member states of the European Union are cooperating on an online forest reproductive materials database for marketing source-identified seed. The relevant directive is based on the knowledge that "quality reproductive material in forestry suited to the site where it is planted is essential for the forests", and assures forest:

- Stability
- Resistance to disease
- Adaptability
- Productivity and diversity.

GREAT BRITAIN

Within the United Kingdom (UK), Forest Reproductive Material Regulations are in place to provide a system of control for seed, cuttings and planting stock that is used for forestry purposes in the UK. This ensures that planting stock is traceable throughout the collection and production process to a registered source of Basic Material. In addition, it provides information on the genetic quality of the stock (Forestry Commission 2007).

2.3 Role of Seed in Policy and Program Implementation

There are many large and small-scale initiatives that have guided our understanding of how and where a robust seed management program benefits Ontario's afforestation and reforestation efforts, now and in the future.

The Government of Ontario has identified several key initiatives, the successful accomplishment of each to some extent dependent on a comprehensive seed management program. These include commitments to report on the State of Ontario's Biodiversity and on progress in achieving Ontario's 15 Biodiversity Targets, ensuring compliance with the federal *Species at Risk Act* (2002) and the provincial Endangered Species Act (2007), as well as delivery of the Invasive Species Policy, and Ontario's Climate Change Action Plan.

Some of the strategies are complementary and recognize that Ontario has a habitat deficit in many parts of the province. Restoring ecological integrity and more natural levels of biodiversity at the ecosystem, species and genetic levels (as recognized in the State of *Ontario's Biodiversity Report Summary 2015* (Ontario Biodiversity Council 2015) requires the restoration of large tracts of woodlands, grasslands, wetlands and unique plant communities. Those re-established cover types must be well-adapted in order to prosper, and that requires an effective seed management program with a chain of custody system and good monitoring so that future managers can learn from past efforts and adapt management accordingly.

Southern Ontario forested landscapes are still recovering from extensive deforestation in the 1800s and early 1900s. Despite significant restoration efforts and gains resulting from tree planting since that time, forest cover in the Mixed Plains Ecozone is again declining according to the *State of Ontario's Biodiversity Report Summary 2015* (Ontario Biodiversity Council 2015). Current measures to conserve biodiversity are not sufficient to prevent loss. Only with improvement will initiatives related to species at risk, invasive species, climate change as well as other landscape restoration programs be successful.

SPECIES AT RISK

Ontario is home to more than 30,000 species and while most are secure, more Species at Risk and Species of Conservation Concern are moving into higher categories than into lower categories. Species at Risk are inextricably linked to habitat loss, and southern Ontario has the largest habitat deficit in Ontario, and across Canada. Restoring primary habitat is highly dependent on the associated native plant communities. When a vascular plant species is at risk, seed is the most cost-effective means of population increase available to recovery programs.

"Seed" is mentioned explicitly in the national *Species at Risk Act* (2002) definitions: "individual means an individual of a wildlife species, whether living or dead, at any developmental stage and includes larvae, embryos, eggs, sperm, seeds, pollen, spores and asexual propagules." The national *Species at Risk Act* (SARA) goes on to recognize "genetically distinct populations" of native plants as worthy of risk designation. Clearly, efforts to track those genetically distinct populations of trees and other plants and to source identify and ensure a chain of custody from seed to planted stock is key to any recovery program.

"When a vascular plant species is at risk, seed is the most cost-effective means of population increase available to recovery programs."

INVASIVE SPECIES

Ontario's *Invasive Species Act* (2015) defines invasive species as "a species that is not native to Ontario, or to a part of Ontario". The Canadian Food Inspection Agency (CFIA) estimates the annual impact of invasive species to be $30 billion ($20 billion in the forest sector, $7 billion for aquatic invasive species in the Great Lakes, and $2.2 billion for invasive plants in the agricultural sector).

Seed from highly invasive species has already changed the quality and resilience of Ontario's native forests and agricultural lands. Invasive plant species such as Norway maple, Buckthorn, Tartarian honeysuckle, Dog-strangling vine and Tree-of-heaven produce copious amounts of seed that germinate readily across a wide range of conditions and their seedlings can out-compete many native species. Preventing their spread by increasing healthy levels of natural forest cover or supplementing native species' populations through planting source identified seedlings will help to maintain the balance of Ontario's natural biodiversity in our most fragmented landscapes.

In Ontario, the MNRF funds and supports programs and organizations that engage research, private sector and individuals on invasive species issues, including the Invasive Species Centre and the Ontario Invasive Plant Council (OIPC). These programs have developed best management practices that promote native alternatives to common non-native garden plants. Released in 2011 in collaboration with horticultural industry representatives, the OIPC's "Grow Me Instead" guides for northern and southern Ontario encourage gardeners to seek locally-sourced native plant species grown from seed. These guides encourage nurseries to increase production of native plants, an effort that must be recognized and supported in ongoing seed management initiatives.

Invasive plants are certainly not the only concern. Butternut canker is an infection found mostly on butternut, first reported in Ontario in 1991, responsible for killing 90% of the this species' population in parts of the US and Canada. The Emerald Ash Borer, native to Asia, has proven to be highly destructive in its new range, killing tens of millions of ash trees and continuing to spread into new areas. In the past few years, trained staff from the Ontario Tree Seed Plant provided support for ex situ recovery programs such as Butternut and assisted with seed collection coordination from ash populations ahead of the Emerald Ash Borer infestation; this seed is now stored for research purposes at the National Tree Seed Centre in Fredericton, New Brunswick. The need for this type of support will continue as Ontario is confronted with increased occurrence of invasive pests.

> "Planting source identified seedlings will help to maintain the balance of Ontario's natural biodiversity in our most fragmented landscapes."

CLIMATE CHANGE

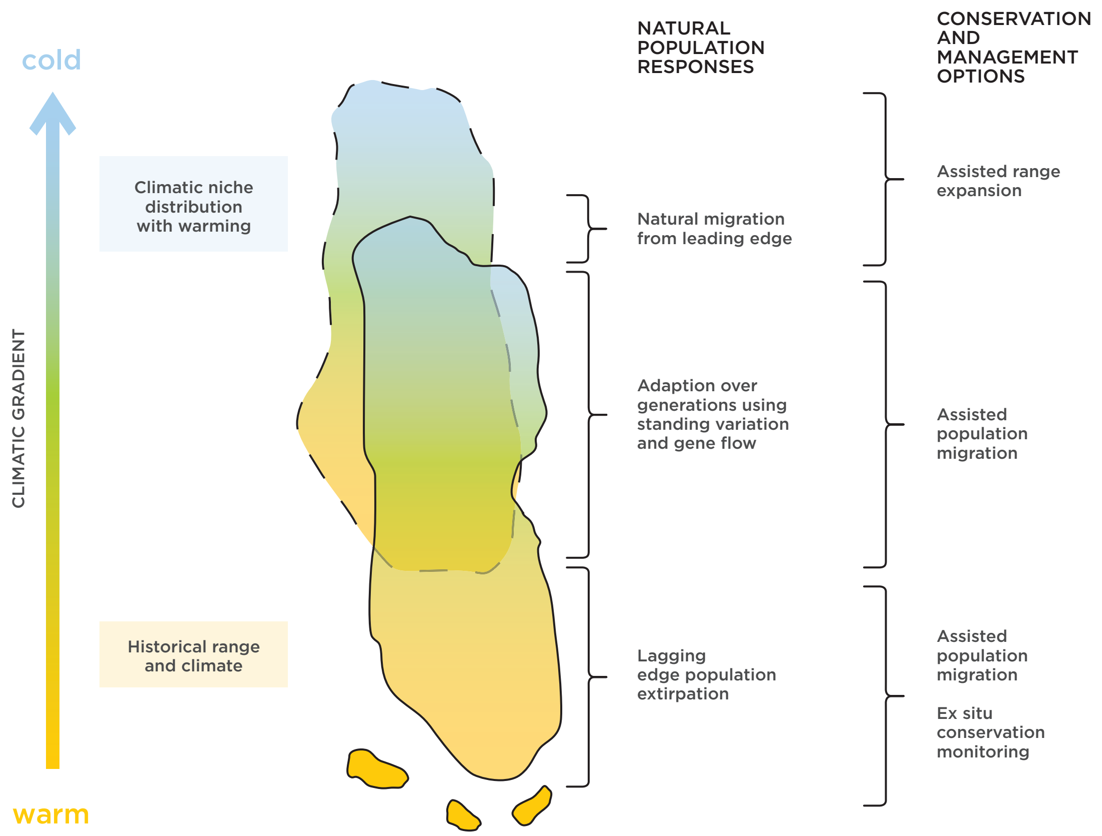
Seed is required to meet Ontario's Climate Change Action Plan commitment to plant 50 million trees by 2025, including two million trees in urban municipalities. Funding support from the Greenhouse Gas Reduction Account (GGRA) is aimed at increasing carbon sequestration and reducing carbon emissions. Maximizing carbon sequestration requires assurance that the right tree is established on the right site, and this requires that managers ensure the right seed is acquired for the right sites. This is a critical component of the objective of increasing forest cover to a recommended minimum of 30%.

The role of seed in supporting forest productivity to maximize carbon sequestration (maximizing growth potential) is identified as a primary adaptation tool by British Columbia's new Climate-Based Seed Transfer system (O'Neill et al. 2017). The MNRF is also reviewing the Seed Transfer Policy to ensure future plantings are best-adapted, and when released will apply to Crown land and to any areas restored under the 50 Million Tree Program (50MTP). Reliance on a centralized inventory to procure adequate supplies of better-matched and source-identified seed sources will be key to managing this transition. Monitoring the success of alternative planting plans will be necessary to employ adaptive management in the face of rapid climate change and encourage non-government mandated programs to follow suit for preserving biodiversity and carbon values. Urban foresters and tree planting agencies are already seeking a greater diversity of species and seed sources in anticipation of the coming climactic changes, which adds complexity to seed planning and management of seed bank inventories.

Large scale, cross-border assisted migration trials such as the collaboration between British Columbia, Alberta and forestry contacts in the western United States led to the planning and installation of 48 test sites with 15 species between 2009 and 2012 as new provenance trials designed with climate change models. These trials aim to shift genetic adaptation from historical geographic ranges into areas where climate will match biological requirements of the species group, typically at one-third or one-quarter of the rotation age. It may also include conservation of unique southerly populations (or entire species) to more favourable habitats before they face risk of extirpation (Figure 4).

On a provincial scale, Natural Resources Canada, MNRF and the Forest Gene Conservation Association, with funding support from the Forests Ontario administered, MNRF funded 50MTP, have installed six assisted migration trials in Ontario (in partnership with local agencies) since 2010. Trials were established to compare local and southerly-sourced seedlots, however a more systematic network of sites and seed sources could provide similar data for the refinement of carbon sequestration models and seed transfer limits on Crown land. Again, design and deployment of such trials requires seed and stock planning well in advance if no source-identified seed bank inventory is available to researchers.

Figure 4: Excerpt from "Assisted migration within species ranges: genetic risks and genomic tools" presentation by Aitken (2012)



3.0

History of Tree Seed Management in Ontario

3.1 Historical Context: Land Clearing and Forest Restoration

Once the best White pine trees were harvested and transported to Britain for shipbuilding, European-Canadian settlers used fire as the primary land-clearing method in southern Ontario. Potash was made from wood ash, and in turn was used to make soap, glass, drugs and other products. In 1821 alone, 35,765 barrels of potash made from burning more than two million mature hardwood trees were exported to Britain. Massive deforestation in southern Ontario was the result of forest clearing for settlement; other demands: steamboats, foundries, brickyards, fuelwood, and the export of valuable hardwood lumber species to the United States. By 1920, about 94% of the original forest south of the Canadian Shield had been cleared (Henry and Quinby 2009).

With so little forest remaining south of the Shield by the mid-late 19th century, farmers began experiencing difficulties producing fruit due to wind damage, spring floods resulting from changes to watershed quality, soil erosion and summer droughts. Apple orchards in Prince Edward County buried in blow sand are evident in archival photographs (Bacher 2011). In 1866, pioneering agriculturists at the Ottawa Experimental Station demonstrated how planting large shelterbelts of conifers could improve yields. However, nurserymen couldn't produce White pine or spruce nursery stock economically and seedlings were expensive to purchase from the United States. "Many nurserymen rear[ing] seedlings for ornamental purposes expect fancy prices. It is, therefore, almost necessary that a nursery be established from which to supply farmers with plant material, for free, or at nominal prices," said Roland Craig in 1903, one of many policy-advising foresters laying the groundwork for establishing the Ontario Tree Seed Plant and provincial nurseries.

Desert-like conditions continued to develop on Ontario's most fragile and exposed soils into the early 1900s, notably in Norfolk, Simcoe, and Prince Edward Counties, and on the Oak Ridges Moraine. Not long after, Chief Forester of Ontario Edmund Zavitz, recognized that massive numbers of trees were required to rehabilitate these "wastelands". He chose native Red pine and White pine for their suitability to these conditions and established St. Williams Forestry Station No. 1 in 1908 to grow trees for free for farmers (Bacher 2011). The Ontario Tree Seed Plant in Angus was established in 1923, initially to support these early rehabilitation programs but later making important contributions to restoration efforts over the following decades. In 1968, Premier John Robarts planted Ontario's One Billionth Tree at the St. Williams Forestry Station. That same year, the national Departments of Fisheries and Forestry reported that Ontario had artificially regenerated 841,000 acres of land, far more than any other province (Cayford and Bickerstaff 1968).

3.2 Demand for Seed: A Historical Timeline

The Ontario Tree Seed Plant was originally part of a fully integrated, provincially managed reforestation system that monitored and implemented the entire process from seed to forest and undertook related tree improvement activities. Demands for seed were driven by provincial efforts to ensure sustainable land management: tree planting from the 1920s until the early 1990s peaked at up to 120 million source-identified trees annually as part of Crown land regeneration, Agreement forest and the *Woodlands Improvement Act* programs. This system changed in 1996 after privatization and the sale of ten provincial nurseries, delegation of seed planning to the Sustainable Forest License (SFL) holders, and responsibilities for Agreement forests were turned over to municipalities. The *Woodlands Improvement Act* was repealed in 1998 and replaced with tax incentive programs for private landowners.

Minimal seed storage capacity existed elsewhere at the time and the Ontario Tree Seed Plant serviced SFL seed banking needs as well as those of private land managers. The OTSP expanded and marketed seed services to other sectors in Ontario, the United States and worldwide.

Private nurseries assumed responsibility for production of native tree and shrub species in the mid-1990s. Those in northern Ontario typically service Sustainable Forest Licensees (SFLs), (tend to be larger clients with demands that are predictable and tied to their own harvest levels, offering sustainable levels of production and the ability to plan for and acquire seed and produce stock). Nurseries in southern Ontario typically service multiple clients, ranging from individual landowners to municipalities to SFLs. Average client requirements are smaller and less predictable, and nurseries must consider this when setting production targets. The 50MTP, announced in 2007 as part of the government's carbon sequestration/afforestation initiative, supports the most significant forest restoration program in southern Ontario and seed supplied from the OTSP forms the primary means of ensuring source-identified stock for that program.

3.3 Coordination, Forecasting and Inventory Management

Since the early years, meticulous manual records have been kept, focusing on cones collected, yield, seed viability, purity data and outbound shipping records. By 1995, MNR(F)'s Tree Seed Database (TSD) streamlined data management and provided inventory reports in accordance with the Seed Zone directive; allowing seed management inventory and data to be accessed at any time. An example of the data provided is included in Figure 7.

Of critical importance in the last 20 years has been the coordination of Ontario's seed collection from experienced, private contractors across the province. Regular contact is necessary to continually update the status of developing seed crops and assign specific collection targets. At any given time there are approximately 40–50 active collectors across the province. The collectors use seed collection supplies: burlap cone bags, seed collection tags and forms, zip ties, and/or cone trays. This ensures that highly perishable products are handled according to best practices to retain seed quality prior to warehousing.

3.4 Capacity to Receive, Process and Clean Seed

Innovations in seed processing and operational improvements in aspects of seed quality continue to evolve. Initial seed processing focused solely on extracting seeds from significant quantities of conifer species. Now, custom combination kiln-tumblers, innovative conveyor systems that prevent seeds from being overheated and damaged, and completely closed dust filtration systems around the extraction equipment and throughout a plant to eliminate the airborne particles both for safety of seed plant workers and mitigate fire hazard are recommended. Plastic tray systems for cone drying and handling are also required.

Additional seed cleaning equipment may include scalpers, de-wingers, maceration units for fleshy berries, custom hot water dip mechanizations for Jack pine (to reduce kiln usage), and liquid separators for upgrading seed quality. Air conditioning and dehumidification equipment is also necessary to protect seed from inclement weather.

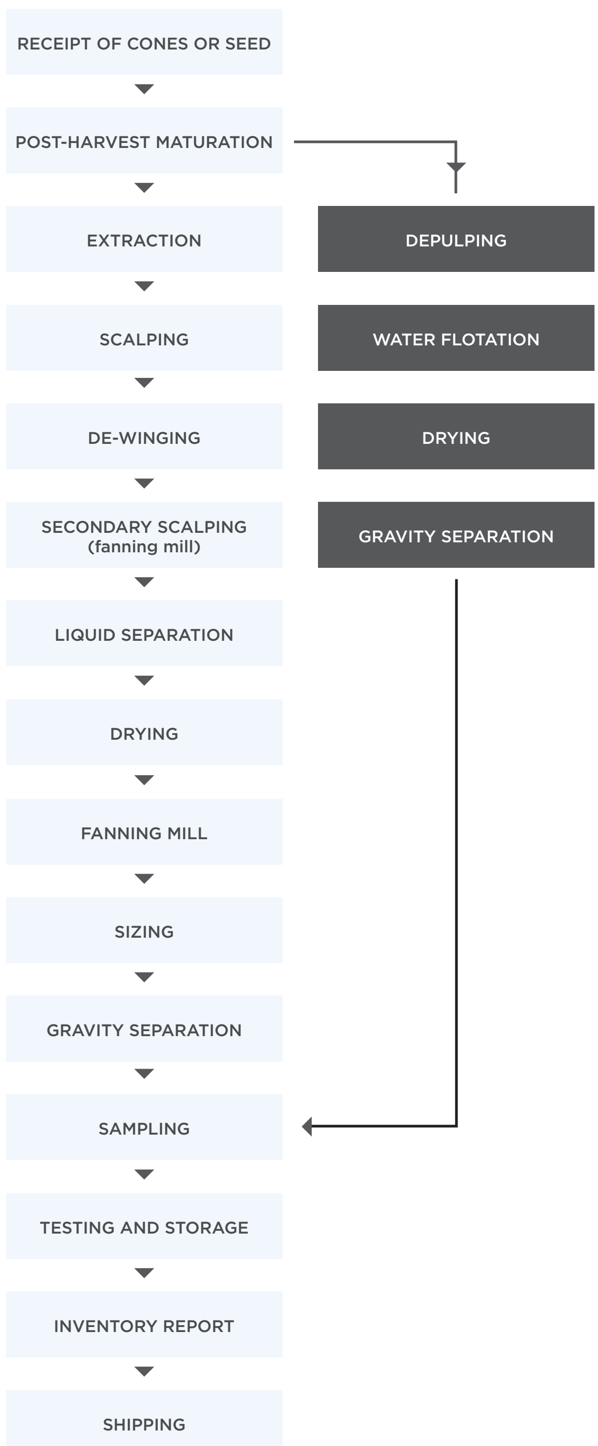
An example workflow of the seed receiving, extraction and cleaning process is provided in Figure 8.

Figure 7: Example of detail required when seed is stored in long-term storage

INVENTORY OF VIABLE SEEDS, BY OWNER AND OTIB ZONE — ONTARIO TREE SEED PLANT

Owner	Species	Seed Zone	OTIB Zone	Collection Type Code	Crop Year	Seedlot No	Viable Seed	Weight Kg	Purity %	Proces. Option	Test Date End	Germination		Germ. Energy	
												Pct	Days	Pct	Days
758	white pine	29	7	00	2005	5332	114,715	2.035	98.1	STD	12 Jun-16	94.25	27	38.5	13
758	white pine	30	7	00	2005	5337	133,870	2.304	99.2	STD	21 Nov-17	91	28	48.5	13
758	white pine	33	7	00	2005	5338	172,164	3.239	99.6	STD	30 May-17	91	28	48	13
758	white pine	34	7	60	2007	5829	143,084	3.378	99.4	STD	06 Jun-17	94.25	27	50.75	13

Figure 8: Seed processing flow chart (Wagner and Columbo (2001)



3.5 Seed Testing & Stratification

The seed of many temperate plant species experience dormancy and are naturally conditioned so that germination will not occur until environmental conditions are suitable, and the probability of seedling survival is higher. By simulating key conditions, dormancy can be broken, and the seeds can be induced to germinate. This process is called stratification and involves exposing seed to the proper combination of substrate, moisture, light and temperature. Some species require specific periods and cycles of cold moist stratification followed by warm temperatures. Dormancy breaking treatments are the basis of seedlot germination testing, with results expressed as a percentage.

Standards and methods for germination testing and other viability tests (tetrazolium and excised embryos being acceptable substitutions in lieu of long stratification periods) have evolved and been refined over the decades. Organizations such as the International Seed Testing Association (ISTA) and Association of Official Seed Analysts (AOSA) have assembled controlled, repeatable protocols and statistical standards for comparable test data to be shared and compared between facilities. ISTA published the *Tree and Shrub Handbook* (Wang et al. 1991) with a full revision due in 2019.

Though ISTA or AOSA lab accreditation has become required in agricultural policy for seed testing standards, protocols for woody plant species are still being researched and improved. However, most forest tree seed banks in Canada use current ISTA standards as a guideline for methodology and consistency. This includes proper sampling techniques from large containers, number of seeds and replicates to use, how to classify normal and abnormal germinants, days to do counts and tolerance levels. Prescriptions are established for each species for initial and recurring germination tests.

Seed Stratification promotes rapid, uniform germination. The *Guidelines for Seed Pretreatment* (Creasey and Myland 1992) provides an in-depth explanation of seed pretreatment (scarification if required (abrasion of hard seed coats to allow moisture uptake), naked stratification, seed monitoring for mould growth and bleach rinses and oversight).

3.6 Long-Term Storage

Many seed banks use cold storage units to maintain seed quality. Refrigeration units keep seeds cool and prolong their life prior to nursery sowing. Freezers achieve –18°C conditions useful for long-term storage and are often buried below ground level for insulation and security. Investment in freezers means high quality seed can be stored for decades.

3.7 Seed Source Chain-of-Custody

In Ontario the protocols for tracking seed source have evolved over the decades both in response to the development of science making the critical link between seed origin, location of planting or seeding site, and subsequent tree health and growth, and the concurrent development of government Policies and Procedures requiring the maintenance of seed source control throughout the regeneration process. In the 1960s, 12 fixed seed zones were tracked and seedlots kept separate in broad areas related to landform and vegetation. In the mid-1980s, these broad zones were subdivided into smaller regional areas (Downey 2017). In 1996, MNR scientists and geneticists produced the Ontario Tree Seed Zone Map and Seed Zone Directive based on provenance and genecology tests with major commercial species (Black spruce, Jack pine, White spruce, White pine and Red oak). The 38 zones were adjusted to align with MNR(F) regional boundaries and informed a conservative approach to metapopulational adaptation for many species without provenance tests.

Record maintenance should involve collector-completed field forms, which collectors are encouraged to include with each cone or seed collection bag with duplicate labels inside and out, with eventual entry of data into the Tree Seed Database. When cones are received they are provided with a cone-lot number. Multiple cone-lots can be combined and once processed (cleaned) they create a seedlot. Once processed, seedlot data is written on storage containers once seed is ready to be frozen.

Seedlots are tracked with a seedlot numbering and data management system. Seed and stock records must be maintained to seed zone or more local area to be eligible to sell stock for use in planting programs on Crown land or when trees are planted with government funds, for instance the 50MTP (as per the Ontario Seed Zone Directive). To improve operational efficiencies some nurseries will combine seedlots, in doing so, most large production nurseries will generate stock lot numbers which are then passed to the purchaser of that stock. In turn, planting agencies are required to maintain that same set of records for each planting project so that there is an uninterrupted chain of custody from seed origin to nursery bed to planting site.

"Planting agencies are required to maintain that same set of records for each planting project so that there is an uninterrupted chain of custody from seed origin to nursery bed to planting site."

"Seed registration identifies seed source and is the essential step to determine genetic quality. Seed identification is based on a seed source number coding system. The Ontario system of numerical codes identifies species, site region, geographic location, agency and collection type. These codes are combined systematically to produce a unique seed source number, which provides a complete identification of the seed origin. Once measured, bagged and tagged with proper seed source identifications, cones are ready for shipment to the Ontario Tree Seed Plant."

(MNR(F) 1996)

3.8 Applied Research, Science Development and Transfer

Beginning in the late 1970s, seed orchards were established for genetic improvement programs. By 1994, the Ontario Tree Improvement Board was managing more than 60 seed orchards, with operational and small lot collection for tree breeding.

In tandem with tree improvement programs, many researchers focused on improving seed quality and quantity. Dr. Ben Wang and D. G. W. Edwards were particularly active on the topic in the Canadian Forest Service and globally. They collaborated with provincial facilities and worked on improving seed quality in trees through experiments in seed maturation timing, handling, processing, testing and longer-term storage. Their research informed many improvements in techniques and processes used, for the betterment of nursery and plantation results. Measurable techniques in drying and freezing high quality seed prolonged the useful life of seed in the freezers for many more years than previously anticipated. Best practices assisted agricultural development of new oilseed crops, and in testing seed improvement methods with native grassland species for restoration. By the late 1980s, seed researchers and practitioners from China, Korea, Sweden, Norway, Great Britain, and other Canadian provinces came to study Ontario's seed management practices.

4.0 Next Steps

4.1 Understanding Supply and Demand

Creating and maintaining a long-term and sustainable supply of biologically-appropriate native seed is a complex undertaking requiring the coordination of effort across a broad jurisdictional landscape that includes upper and lower tier municipalities, Conservation Authorities, government, private nurseries, and individual contractors. Effective coordination ensures efficiency and effectiveness within and between each of the discrete activities contributing to a successful seed program.

If recent trends persist, that is, an increase in the number of municipalities setting mandates to use seed source identified stock in their urban forestry programs, there will be significant need for additional seed management services. The recognition of this importance is predicted to grow. If all tree planting programs consolidate their demands, native seed collectors and stock producers would be better able to respond to needs.

To properly and accurately quantify native plant demand in the future, surveys such as the 2017 Municipal Tree Survey are important benchmarks, however only for the most commonly used municipal stock type (caliper). The 1995 Native Plant Use and Production survey by Landscape Ontario and OMAFRA (Kessel 1995), if revisited, could help characterize the entire commercial nursery and design/restoration sectors. There may also be unknown seed storage needs from other specialized seed sectors that could be included in demand for facilities and support services, i.e. First Nations seed projects, Seed Savers Exchange, Species at Risk recovery teams, post-secondary environmental study programs, botanical gardens, etc.

The diversity of species and sectors needs in southern Ontario, particularly with the initiation of the 50 Million Tree Program in 2007, has renewed interest in seed collection. Particularly in the southwestern portion of the province, planting programs are projected to increase the diversity of hardwood species planted versus traditional conifer plantation. Seed processing expertise, equipment and protocols continue to need development with regards to improving seed quality and collecting efficiency.

To ensure success, an optimal seed management program requires:

- **Species diversity**
- **Seed quality assurances: germination percentage and seed source**
- **Reliable seed availability year to year, Broad technical training**
- **Full suite of seed services and species (conifer and deciduous) in one location**
- **Mechanisms to manage seed in a changing climate, Applied seed research**

Developing pressures (climate change, invasive species, species at risk) create risk but also present significant opportunities in our future seed management efforts. These include:

- The potential to expand into native species that have been underutilized in the past but for which these developing pressures will create demand
- The opportunity to set fees by species
- Taking a leading role in applied seed research
- Enhancement of the chain of custody tracking systems and processes already in place.

4.2 Opportunities for Collaboration

Long-term seed banks exist to ensure forest resources are available through periods of reduced activity or developing pressures with minimal genetic or economic loss of the investment. Government, non-profit organizations, private industry, independent contractors, nurseries and seed processing facilities, if working collaboratively, have the potential to find cost and organizational efficiencies that will meet Ontario's ecological and business requirements going forward.

A well-orchestrated collaborative could take on these necessary functions:

- Seed crop forecaster and certified seed collector training
- Utilizing seed to prepare for climate change
- Seed orchard maintenance and development
- Ontario's Seed Collection Area Network (SCAN)
- Collaborative seed collection target allocations
- Seed collection
- Seed shipments and receiving
- Database and seed inventory management (maintaining chain-of-custody)
- Seed extraction and processing options by species
- Seed testing and stratification by species
- Short and long-term seed storage
- Management of seed surplus.

4.3 Opportunities for Long-Term Success

The need for long-term planning for seed has never been more critical in Ontario than it is right now; current and future forest conditions arise from the right quantities of seed in the right species from the correct sources.

There are several developing opportunities that may lead to increased support for more forests and all of the values that they provide. Long-term seed management planning. will enable practitioners across Ontario to consistently plant the right tree on the right site, ensuring optimal growth potential, and thus intact and thriving forests. Opportunities include:

Building with Wood - Supportive initiatives such as the development of large-scale structural wood systems, including heavy timbers, engineered framing systems, and other modern wood products, have the potential to contribute to an expansion of the industry.

Carbon Markets - Proceeds generated from emitter-based carbon allowance auctions are intended to be used to invest in greenhouse gas (GHG) reduction activities such as tree planting programs including the 50 Million Tree Program.

Restoration Programs - Species at Risk recovery strategies and the promotion of pollinator habitat will likely require restoration programs built on the need for suitable seed sources to ensure the presence and prevalence of suitable habitat.

Building Out-of-Province Relationships - Ontario nurseries and seed user groups may build relationships with seed storage and processing facilities within and out-of-province. This will improve seed literacy in Ontario. In addition to this, opportunities will arise to develop relations with the northern United States, especially as it relates to climate change and the need to incorporate southern seed sources into long-term seed inventories.

Seed from Non-Tree Species – While seed from native tree species will be the initial priority, the system should accommodate native shrubs and grassland species as well, when policy and markets allow. A comprehensive system will allow for native seed from the full range of species groups required for restoration purposes to be included, be it woodland, grassland or wetland. The costs of developing the expertise to properly incorporate these species into a program must be determined, as will the potential markets and investment recovery.

Native Seed Partnership — Working toward a collaborative system of securing biologically appropriate native and source-identified seed is clearly in Ontario's long-term interest. The inefficiency of allowing competing interests with independent processes to develop, or to by default encourage a reliance on commercial seed houses that may facilitate the use of seed of unknown origin and invasive species, will lead to the degradation of native forests, continued stress on biodiversity, increased instances of species at risk and limited options for future adaptation to climate change. There is an opportunity to establish a network of conservation minded and mandated organizations, companies, governments and individuals with a keen interest in seed conservation, forest genetics, willing to contribute to a provincial level program.

4.4 Requirements for Further Consultation and Study

A broad range of uncertainties and challenges were identified by users in January 2018, and need to be considered during the preparation of a seed program feasibility study as well as during delivery model development. To varying degrees those challenges affect each of the following business-related functions:

- Seed crop forecaster and certified seed collector training
- Utilizing seed to prepare for climate change
- Seed orchard maintenance and development
- Ontario's Seed Collection Area Network (SCAN)
- Collaborative seed collection target allocations
- Seed collection
- Seed shipments and receiving
- Database and seed inventory management (maintaining chain-of-custody)
- Seed extraction and processing options by species
- Seed testing and stratification by species
- Short and long-term seed storage
- Management of seed surplus.

Non-profit organizations, private industry, independent contractors, nurseries and seed processing facilities, if working collaboratively, have the potential to find cost and organizational efficiencies that will meet Ontario's ecological and business requirements going forward.

5.0

A Vision for the Future of Seed Management: Conclusions and Recommendations

The optimal seed management program is multi-layered. At the most basic level the program will meet initial requirements of science-based operational nursery stock production and related afforestation programs, with a focus on the identification, acquisition, treatment, storage and distribution of high quality native, source-identified seed. In addition to this, any successful program must have capacity to respond to:

- Developing government policies and priorities
- Newly evolving science
- The unpredictable nature of seed crop occurrence, and to respond to bumper crop conditions for species with very irregular seed crops by, at short notice, greatly increasing planned collection expenditures. Related to this is the need to develop the required capacity to store seed for extended periods before resale, so that sufficient quantities of viable seed are available even through potentially many years of seed crop failure
- The requirement to provide service where collection and tracking from the full range of seed zones from which stock is required, including sometimes very small seedlots or seed from species that have high ecological value but currently low commercial demand (e.g. Carolinian species).

Table 4: Elements of a complete native seed management system

SEED DEMAND FORECASTING	Confirm number of seeds of each species required by all conservation and restoration agencies. Nurseries typically require up to 3 years to produce a seedling, e.g. seed must be collected in 2018 in order to produce tree seedlings for 2021.
SEED CROP FORECASTING	Monitor seed crops developing on 120+ tree species across Ontario in order to be in a position to organize collections when and where the desired crops occur.
SEED COLLECTION	Coordinate a seed collector network to facilitate collectors' essential role in providing high quality seed that is source documented, assign targets to collectors, receive cones and fruits, make payments, and appropriately store thousands of bags of cones and trays of fruit each year until they can be processed.
SEED EXTRACTION	High quality extraction of seeds from cones and fruits, and sort, clean and dry, as appropriate.
SEED STORAGE	Long-term (up to 20 years) high quality storage in humidity monitored freezers, seed quality monitoring and regularly testing for viability.
SEED SOURCE TRACKING	Maintain chain of custody throughout the seed handling process to ensure seed of known origin is available to produce nursery stock appropriate for planting sites across Ontario.

Maintaining and enhancing biodiversity, particularly for species at risk and pollinators, reducing the impact of invasive species, and improving resilience of our natural landscapes to climate change all point to the need for more ecological restoration in Ontario. Having a secure and sufficient supply of viable, locally adapted, source-identified, biologically appropriate native seed is a critical foundation for all ecological restoration efforts. Native seed produces planting material that is genetically adapted to the local climate and environment. Native seed and stock supports local ecology and food chains. Native is best, seed source identification is critical. To raise awareness and encourage action, the following recommendations are presented:

CURRENT STATUS

Take stock of current seed initiatives and identify the infrastructure required to meet future needs.

INFRASTRUCTURE DEVELOPMENT

Develop and support, on a long-term and sustainable basis, the infrastructure required to enhance and maintain Ontario's seed management program.

DIALOGUE AND COLLABORATION

Continue to facilitate dialogue and collaboration among existing and new partners from all relevant disciplines including Conservation Authorities, stewardship groups, forest industry, environmental advocates, academia, private seed collectors, landowners and government.

RESEARCH

Support new and ongoing research to determine the quality, quantity, and proximity of seed and update best practices as technology progresses and environmental changes (i.e. climate change, invasive species) advance.

AWARENESS

Increase awareness of the need for healthy, diverse and adaptable tree seed. Relate it to the health and prevalence of trees and forests and support for forest restoration initiatives. Focus on the media, general public and political representatives.

POLICY

Create a provincial inter-ministerial committee to improve the policy and planning framework for land use, natural environments, and forest planning/management through greater understanding of the need for continuous and stable native, seed sourced seedling production as the basis for future restoration activities. Include ministries such as Natural Resources, Environment, Municipal Affairs and others.

NOTES

6.0

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Factsheet on Roadside Vegetation Management: https://www.beyondpesticides.org/assets/media/documents/infoservices/pesticidesandyou/documents/UpdatedROW.pdf

Reference to CFIA impact of invasives: http://www.inspection.gc.ca/about-the-cfia/accountability/reports-to-parliament/2013-2014-dpr/eng/1409769354767/1409769355486?chap=0#c32s3c.

Climate Change

Ontario's Climate Change Action Plan: https://www.ontario.ca/page/climate-change-action-plan

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Appendix A: The Science of Seed Banking

In order to effectively manage living and viable seed as a natural and genetic resource, technical knowledge and training are required. The scientific foundations of long-term seed banking are as follows:

TYPES OF SEED

First, an in-depth knowledge of types of seed needed, seed forecasting and collection, as well as handling and storage are vital to ensure an adequate and long-term supply.

Orthodox: Seed can be dried, without damage, to 5–10% moisture content (wet weight basis, ISTA 1993), moisture levels that are usually much lower than normally achieved in nature. Seed longevity increases with reductions in both moisture content and temperature, in a quantifiable and predictable way. Seed considered "orthodox" include those of many agricultural crops, grasses, legumes, conifer trees, ash, birch, cherries, dogwoods and sugar maple.

The ability of seeds to tolerate desiccation is optimized close to or after the point of natural maturity. If orthodox seed is immature when collected, or poorly handled after collection or during seed processing, storage time and viability can be dramatically reduced with clear consequences to seed quality and to treatment effectiveness.

Recalcitrant: Seed cannot survive drying below a relatively high moisture content (often in the range 25–50% wet basis) and cannot be successfully stored for long periods. Cryogenic storage of embryos is possible with this type of seed and researched is ongoing, but the process is yet used operationally. Species considered "recalcitrant" include but are not restricted to: oaks, Silver maple, Ohio buckeye and American chestnut.

Intermediate (sometimes called sub-orthodox): Seed are more tolerant of drying than recalcitrant species but tend to lose viability at faster than orthodox species. They do not conform to all the criteria defining orthodox seeds, especially in respect of the quantification and predictability of the relations between longevity and both drying and cooling. Native tree species in this category include walnuts, hickories, American beech, and red maple.

SEED BANKING "RULES OF THUMB"

To extend the longevity of orthodox and sub-orthodox seeds that can tolerate desiccation, seed scientists have discovered predictable rules and standards, with important emphasis on reducing seed moisture first and then managing temperature to reduce slow metabolic rates. Drying seed also reduces damage from fungi, insects and microbes.

Exact protocols are species-dependent, and methods are adjusted to the capacity of facility equipment and objectives. For seed forecasting basics, please refer to the *Seeds of Ontario Trees and Shrubs Manual* (FGCA 2014).

Rule #1: Seed Quality

High quality seed will maximize the benefits of seed banking.

Each seed collection is measured by its genetic and physiological quality and cannot be judged by visual appearance alone. Cut tests provide an important quality field check to assess if embryos are present, healthy and filling 90–100% of the corrosion cavity (Figure 5).

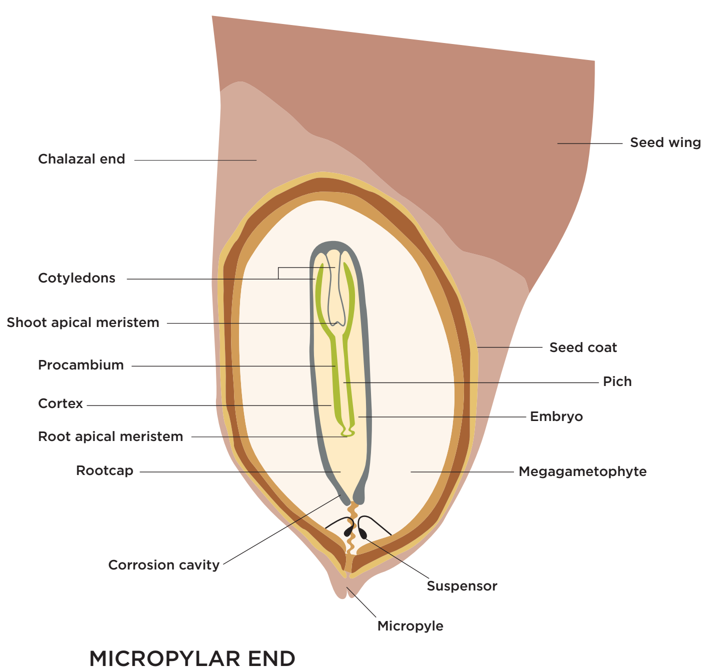
A high genetic quality seedlot implies that:

- Documentation identifies the known origin, so a manager can direct the genetic potential of the stock to an area identified by science or policy as most suitable for growth (putting the right tree on the right site)
- The seedlot is not hampered by any deleterious genetic bottlenecks (temporary but significant reductions in population size) such as isolated self-pollination
- The volume of seeds meets sufficient genetic diversity sampling targets.

A high physiological quality of a seedlot implies that:

- The seedlot was collected from cones or fruit with little or no damage from insects or disease
- Healthy seed with fully developed embryos was collected at optimal maturity, and close to time of typical natural dispersal, which means desiccation tolerance is also at or near its maximum
- Seed is handled and processed according to best practices suitable to the species, maintaining viability and vigour (i.e. control of temperature, moisture, ventilation, proper methods of extraction to minimize seed damage). Seed damage is cumulative so attention to detail and perishability is critical to maintain quality through processing
- Clean seedlots are stored under suitable conditions based on the species' seed behaviour.

Figure 5: **Generalized seed anatomy of a conifer seed cut longitudinally (*British Columbia Seed Handling Guidebook* (Kolotelo et al. 2001))**



Seed longevity can be extended under controlled storage conditions, but seed behaviour, natural aging processes and death of individual seeds in a seedlot follow a sigmoidal curve and eventually lead all stored seedlots to lower viability and vigour. Initial germination tests of fresh seed (K_i) and seed moisture content is an important factor in equations used to predict seed viability and storage life (Flynn and Turner 2004).

Rule #2: Seed longevity: moisture content, relative humidity

Seed longevity doubles for every 1% reduction in moisture content or 10% reduction in relative humidity.

The hygroscopic nature of seeds means tissues will equilibrate to the humidity of their surroundings. For long-term storage, seed must be sufficiently dried to 5–10% moisture content (wet weight basis, ISTA 1993) prior to frozen storage so ice crystals do not form within cell tissues. Freezing damp seed destroys or severely damages the seed's ability to germinate and develop normally. The same moisture content range also applies to drying pollen for frozen storage.

Moisture content is most accurately determined using moisture testing standards set by the International Seed Testing Association (ISTA). Weighing samples prior to oven drying at 103°C ±17 hrs., and then remeasuring will allow for the evaporated moisture to be calculated as a percentage of weight. This rule applies to large and thick-coated seeds.

Non-destructive methods using water activity (A_w) meters are being explored, which is translatable into the more widely understood equilibrated relative humidity (eRH%). Water activity/eRH% has the additional bonus of achieving similar moisture content of seeds with varying chemical compositions, i.e. seeds with a high oil content store less moisture than those high in carbohydrates. Measurements must be taken at room temperature, around 20–25°C, with seed that is also at the same temperature. Several North American seed banks use water activity standards prior to or for monitoring seed in frozen storage:

- BC's Tree Seed Centre has set 35% eRH ± 5% eRH as their acceptable range (Duke 2014)
- Quebec has set operational standards of 33–38%eRH to determine seed is sufficiently dry for storage (Colas, TSWG Bulletin No. 58, December 2013)

- Alberta has set 15–25% eRH at 20–30°C for long-term conservation seedlots, based on cost-effective ambient conditions they can achieve at their Smoky Lake facility and Lindsay Robb's experience at the Millennium Seed Bank in England. Several other seedbank managers feel this target is too aggressive, requires too much energy, and may cause imbibition damage, particularly of hardwood species, when seeds are rehydrated (JD Simpson, pers. comm)

In central and northern Ontario, ambient conditions are relatively humid and not ideal for equilibrating seed to recommended moisture contents except in the months of January–April when temperatures below –10°C lead to drier ambient air. However, climate change predictions of warmer winters and more frequent thaws may limit weeks of ideal humidity. Spring, summer and early fall conditions make it difficult in many places to sufficiently dry seed or prevent moisture reabsorption when working with seed (Kolotelo, TSWG Bulletin No. 60, December 2014).

Achieving recommended conditions requires heated kilns to open and tumble cones and release seed, sealed seed dryers for conditioning seed or drying after liquid separation, and sealed, dehumidified rooms to prevent moisture reabsorption after drying.

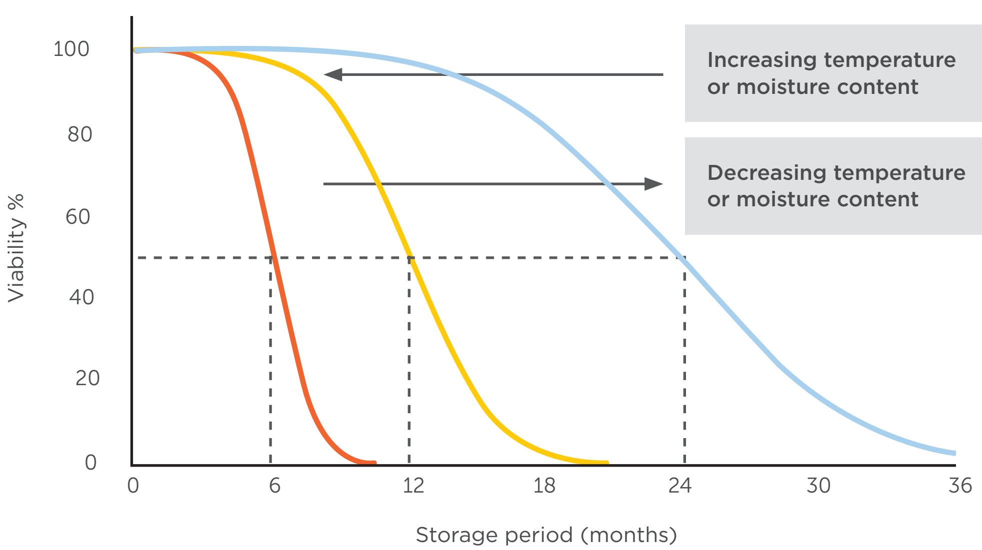
Rule #3: Storage after drying

After drying, seed longevity doubles for every 10°F (5.6°C) decrease in temperature.

After proper drying, long-term freezer storage at –18°C (±2°C) is recommended and used by many international seed banks for all orthodox species to maximize storage life and viability for medium and long-term use (Millennium Seed Bank Partnership Kew 2015). Figure 6 provides a generic survival curve at 20°C, with viability referring to germination percentage of a representative sample (Bradford, 2012).

Not all managers intend to keep seed for extended periods of time and can lower their operating budgets with less demanding infrastructure. Analysis of existing operational seed storage solutions for short and medium-term storage (5–15 years) indicates that –3°C, –7°C and –10°C are suitable for most species provided inventory renewal and seed moisture monitoring regimes are adjusted to suit seed survival curves.

Figure 6: Generic seedlot survival curve at 20°C.



Rules #2 and #3 have also been simplified for basic seed preservation (primarily with home gardeners and agricultural crops) where seed life is extended (by no quantitative value) if the sum of ambient temperature (°C) plus the relative humidity (RH%) does not exceed 100.

Rule #4: Control moisture while storing

Seed must not reabsorb moisture until the user needs to stimulate germination.

Many seed banking resources discuss sealing seed in an airtight container to maintain stable moisture content of the seed in storage yet excluding moisture in the air is a difficult technical standard to achieve because very few materials or systems are truly impervious to water diffusion. A recent test of materials available for seed banking demonstrated those that are optimally suited to excluding moist air for at least 70 days at any temperature regime are:

- Mason jars with clamped seals using natural rubbers are most effective, but downsides include the storage area required by round jars versus square, weight and the potential for breakage
- Glass bottles fitted with polypropylene lids outperformed glass bottles with metal caps
- Tri-laminate foil bags sealed with a heated seal
- Only a few specific brands of plastic containers tested in Alberta passed the 70-day test (Robb, TSWG News Bulletin No. 60, December 2014).

Most operational seed banks in Canada use large rigid high-density polyethylene or polypropylene containers with screw lids to store large volumes of seed. The time to allow seeds to come to room temperature, frequency of opening the container and volume of seed remaining within the container returned to storage will contribute to moisture absorption over time unless working within an enclosed dehumidified space. Standards and protocols vary with regards to retesting of moisture content or water activity, and reconditioning to the original values before returning to storage.

Containers must be filled or dominated by seeds to maintain stable levels of humidity when samples or portions are removed, especially if this is not done in a dehumidified space. When the container is open, moisture will flow in, but volume of the air space relative to the volume of seeds will determine how much effect this will have. Access to various sized containers to allow downsizing of smaller seedlots can help maintain storage life.

Building and maintaining a sustainable and high-quality seedbank capable of meeting the long-term provincial requirements therefore begins with the acquisition of high quality seed, a critical step that assumes that training mechanisms are in place to ensure collectors and harvesters can identify the seed quality characteristics and indicators that are required.

Seed managers and storage facilities must understand the importance of maintaining and monitoring temperature and relative humidity levels, often with modifications required for various species, in extending the viability and regenerative energy of the seed in storage. The challenge of course is that the necessary skill sets required for each stage of management can take years to develop and perfect. Therefore, processes must be documented and technical skills need to be passed on to the next generation of professionals in order to ensure the health, diversity and abundance of our future forests.

Appendix B

Example of Bulk Seed Price List

Species	Latin Name	Price per 1000 Viable Seeds	Price per Kilogram	Price per Pound	Average Seeds per Gram	Average Germination %
White pine	*Pinus strobus*	$5.11	$225.00	$102.27	55	80
Red pine	*Pinus resinosa*	$2.70	$260.00	$118.18	112	86
Jack pine	*Pinus banksiana*	$1.21	$320.00	$145.45	294	90
Scots pine	*Pinus sylvestris*	$2.29	$270.00	$122.73	128	92
Austrian pine	*Pinus nigra*	$7.63	$250.00	$113.64	43	76
White spruce	*Picea glauca*	$0.95	$370.00	$168.18	460	85
Black spruce	*Picea mariana*	$0.36	$320.00	$145.45	987	90
Red spruce	*Picea rubens*	$1.43	$460.00	$209.09	339	95
Norway spruce	*Picea abies*	$1.86	$185.00	$84.09	124	80
Hemlock	*Tsuga canadensis*	$1.98	$330.00	$150.00	334	50
White cedar	*Thuja occidentalis*	$0.50	$275.00	$125.00	717	76
Tamarack	*Larix laricina*	$4.91	$1865.00	$847.73	506	75
European larch	*Larix decidua*	$10.20	$880.00	$400.00	146	59
Japanese larch	*Larix leptolepis*	$2.47	$350.00	$159.09	205	69
Red maple	*Acer rubrum*	$2.35	$6.00	$27.27	51	50
Silver maple	*Acer saccharinum*	$5.69	$40.00	$18.18	8	90
Black cherry	*Prunus serotina*	$158.73	$200.00	$90.91	14	9
Black locust	*Robinia pseudoacacia*	$2.58	$120.00	$54.55	57.5	81
Honey locust	*Gleditsia triacanthos*	$26.79	$60.00	$27.27	7	32
Thornless honey locust	*Gleditsia triacanthos inernis*	$26.79	$60.00	$27.27	7	32
Colorado blue spruce	*Picea pungens*	$2.02	$450.00	$204.55	227	98
Mugho pine	*Pinus mugo*	$2.78	$300.00	$136.36	135	80
Black elderberry	*Sambucus canadensis*	$2.97	$320.00	$145.45	598	18
Red elderberry	*Sambucus pubens*	$1.40	$250.00	$113.64	617	29
Juneberry	*Amelanchier spp.*	$8.19	$640.00	$290.91	186	42
Redbud	*Cercis canadensis*	$1.73	$50.00	$22.73	36.1	80
Red Osier dogwood	*Cornus stolonifera*	$3.63	$105.00	$47.73	43.8	66
Kentucky coffee tree	*Gymnocladus dioicus*	$173.58	$46.00	$20.91	0.5	50
Choke cherry	*Prunus virginiana*	$11.43	$46.00	$20.91	16.1	25
Staghorn sumac	*Rhus typhina*	$16.39	$120.00	$54.55	12.0	61
Am. mountain ash	*Sorbus americana*	$1.50	$250.00	$113.64	265.4	63
Nannyberry	*Vibumum lentago*	$11.98	$100.00	$45.45	16.7	50
A. Highbush Cranberry	*Vibumum trilobum*	$9.41	$160.00	$72.73	34.0	50
Grey dogwood	*Comus racemosa*	$10.08	$100.00	$45.45	32.0	31
Silky dogwood	*Comus amomum*	$3.03	$50.00	$22.73	30.0	55
Alt leaf dogwood	*Comus altemifolia*	$7.14	$50.00	$22.73	14.0	50
False Solomon’s seal	*Maianthemum racemosum*	$6.05	$115.00	$52.27	38.0	50

Appendix C

Established optimal pretreatments and standard conditions for germination of selected Ontario tree species

(from Wagner and Columbo, 2001)

	PRE-TREATMENT		GERMINATION CONDITIONS		
Species	Method	Time (days)	Temperature (˚C)	Light hours	Germ. test period (days)
Black ash	Warm strat.[a] Cold strat.	60 90	— 20–30	— —	— 60
Green ash	Warm strat. Cold strat.	60 90	— 20–30	— 8	— 60
White ash	Warm strat. Cold strat.	30 90	— 20–30	— —	— 60
White birch	Aerated soak	1	20–30	16	21
Yellow birch	Cold strat.	21	20–30	8	21
Balsam fir	Cold strat.	28	20–30	8	21
Eastern hemlock	Cold strat.	90	20	8	28
Eastern larch	Cold strat.	60	20–30	8	21
European larch	Cold strat.	21	20–30	8	21
Japanese larch	Cold strat.	21	20–30	8	16
Black locust	Acid soak[b] Cold strat.	1 hr. 30	— 20	— —	— 21
Red maple	Cold strat.	45–60	20–30	8	21
Silver maple	—	—	20–30	8	14
Sugar maple	Aerated soak at 2˚ to 3˚C Cold strat.	14 42	— 20–30	— 8	— 28
Red oak	Cold strat.	30–45	20–30	8	14
Black spruce	Aerated soak[c]	1	20–30	8	16
Norway spruce	Cold strat.	21–30	20–30	8	21
Red spruce	Aerated soak	1	20–30	8	28
White spruce	Cold strat.	21	20–30	16	21
Jack pine	Aerated soak[c]	1	20–30	8	14
Red pine	Aerated soak	1	20–30	8[d]	14
White pine	Cold strat.	60	20–30	16	28
Tulip tree	Cold strat.	60–90	20–30	—	28
Black walnut	Cold strat.	90–120	20–30	—	28
Northern white cedar	Cold strat.	21–30	20–30	8	21

[a] Stratification treatment can be done either with a moist medium of peatmoss, sand, or mixture in a container, or without a medium by soaking seeds in aerated tap or distilled water for 24 hours draining the water, surface drying the seeds, placing them in 2 to 4 mil thick plastic bags with the top loosely tied, and storing in darkness at a temperature of 20˚C for warm and 2˚ to 4˚C for cold stratification for the specified number of days. For the best results, the bags should be opened weekly, shaken gently to facilitate air exchange, and returned to the proper temperature regime.
[b] Seeds should be soaked in concentrated H_2SO_4 for on hour to scarify.
[c] Stratification is not required for full germination. However, cold stratification for two weeks is recommended to stimulate fast and uniform germination.
[d] Though not essential for maximum seed germination for red pine, light helps early seedling development.

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