Mountain Marathon: Endangered Limber and Whitebark Pine Recovery in Alberta

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ABSTRACT

Work to recover endangered whitebark and limber pine in Alberta has been underway for over two decades. A summary of the provincial recovery and restoration program is described here. The species' slow growth, remote habitats, irregular cone crops, and non-commercial status pose unique challenges. Their large, nutrient-rich seeds are a key source of food for wildlife species in these habitats, supporting a unique relationship with Clark's nutcracker. Their persistence in extreme sites helps anchor fragile soils, sustain hydrological function in montane headwaters that support endangered salmonid populations, and initiate treeline formation. Mitigating the main threats causing their decline requires a multi-pronged, sustained effort focused on disease resistance genetics at multiple scales. Identifying and testing a genetically diverse base of well-adapted, disease-resistant trees to provide seed for natural and artificial regeneration is the core of the Alberta recovery program. This is complemented by landscape-level strategies to reduce threats caused by mountain pine beetle pressure and wildfire risk. Promoting knowledge of the value of and threats to these species raises awareness and helps avert and mitigate direct human impacts. The ranges of whitebark and limber pine cross jurisdictions and require active partnerships across borders to make recovery a success.

INTRODUCTION

Whitebark (*Pinus albicaulis*) and limber pine (*Pinus flexilis*) trees are Endangered in Alberta as a result of rapid population decline caused by shared threats. In B.C., both species are Blue-Listed (threatened). Whitebark pine is Endangered federally in Canada and limber pine is pending a federal listing decision after the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assessed it as Endangered. These keystone species provide many unique and valuable ecosystem services, the most important provided by their uniquely large and rich seeds as a food source to numerous wildlife species (COSEWIC 2010, 2014). Other important functions include moderating headwater flows in bull trout (*Salvelinus confluentus*) and cutthroat trout (*Oncorhynchus clarkii*) habitat, anchoring steep and fragile soils, catalyzing upper treeline development, and supporting important cultural values for many Indigenous nations, and place-based experiences for people who recreate and support livelihoods in these areas.

The main threats to the species in Alberta are the introduced fungal pathogen causing the fatal disease white pine blister rust (*Cronartium ribicola*) and mountain pine beetle (*Dendroctonus ponderosae*). Ancillary threats interacting with them, and with each other, include changes to wildland fire regimes leading to successional replacement by more shade-tolerant competitors, mortality caused by larger, more extreme fires related to fire suppression and climate change, and the various detrimental climate change impacts on high-elevation species. Recovery plans contain actions to mitigate each threat and support the goals of genetically diverse, self-sustaining populations of these species throughout their ranges. Whitebark and limber pine grow very slowly, adapted to their severe habitats, so recovery requires a commitment on the order of a century: a single tree generation. The remote areas they grow in pose unique logistical challenges and add high access costs. Sharing resources, knowledge and data across jurisdictions has enabled agencies to enhance capacity and achieve what no single jurisdiction or agency could. The Alberta whitebark and limber pine recovery program is outlined here, including achievements to date.

RECOVERY PLANS

Federal Status and Plans

Both species share biological and ecological characteristics, are impacted by the same threats (with some regional differences), and therefore have similar recovery plan goals and actions. Whitebark pine was assessed as Endangered in 2010 by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2010) and listed on Schedule 1 of the *Species At Risk Act* (SARA) in 2012. The draft federal recovery plan (Environment Canada 2017) is still pending finalization. Limber pine was assessed as Endangered by COSEWIC in 2014, and is still pending a SARA listing decision, which will trigger development of a federal recovery plan.

Implementation is coordinated by a working group of technical, management, and communications specialists from agencies and jurisdictions where whitebark and limber pine grow. Participants represent Parks Canada Agency, departments of the provincial Alberta and British Columbia (B.C.) governments, and the Whitebark Pine Ecosystem Foundation of Canada. A series of facilitated Conservation Standards (formerly Open Standards) workshops convened by Parks Canada Agency and now hosted by the Whitebark Pine Ecosystem Foundation of Canada began in 2018. This process has resulted in the development of recovery goals, objectives, indicators, and pathways for action.

Provincial Status and Plans

In 2008, Alberta listed whitebark and limber pine as *Endangered* under the *Wildlife Act*. A provincial recovery team included members from provincial and federal government agencies and non-government organizations, with stakeholder meetings including industry representatives. The responsible Minister approved recovery plans developed by the team for each species (Alberta Whitebark and Limber Pine Recovery Team 2014a,b). Implementation then became the focus, with recovery team membership consolidated to provincial government. Co-chairs represented Alberta Environment and Parks and Alberta Agriculture and Forestry, supplemented by team members with diverse expertise. The recovery plan was completely revised in 2019 (pending approval) to combine both species and integrate streamlined Open Standards objectives and targets. In 2020, Alberta Agriculture and Forestry reduced their involvement and the Whitebark Pine Ecosystem Foundation of Canada became co-chair; at the same time, external experts and agency representatives were added to the team.

Related plans support specific aspects of recovery. Both in situ and ex situ gene conservation plans for the province provide snapshots of the status for native Alberta tree species and identify conservation gaps and priorities (Alberta Agriculture and Forestry 2018a,b). Recovery and restoration plans have been developed throughout the species' ranges, including a range-wide U.S. strategy supported by the Whitebark Pine Ecosystem Foundation (Keane et al. 2017; Tomback et al. 2022). Restoration work in U.S. National Forests (Jenkins et al. in press), National Parks, the Greater Yellowstone area, Bureau of Land Management lands (Perkins et al. 2016), and some Tribal Lands is guided by whitebark and limber pine restoration plans. B.C. has plans in place for several regions and provincial parks (Clason 2013, Wilson and Stuart-Smith 2001), and the province developed an implementation strategy [in review, K. Bennett, BCMFLNRORD, personal communication]. The Crown Managers Partnership High Five Working Group developed a spatially explicit whitebark and limber pine restoration strategy covering the Crown of the Continent Ecosystem (Jenkins et al. in press) that Alberta will be implementing. Parks Canada has incorporated these species in their Multi-Species Action Plans (Parks Canada Agency 2017a,b,c); and there are numerous mitigation plans and best practices for specific activities and regions to reduce direct impacts to and improve outcomes for these species.

The long-term provincial recovery plan goal is: "to have at least one self-sustaining metapopulation per species and per management unit, of sufficient size, composition, and distribution to sustain Clark's nutcracker populations within the historical range of whitebark and limber pine and support adaptation in their projected future range." Supporting objectives are based on regional threats and impacts. Strategies are outlined to meet objectives, with progress measures and actions required for each objective (table 1). The slow growth and maturity of these trees, which do not begin producing cones until age 50 (limber pine) to 80 (whitebark pine) years means that objectives ultimately aim a century down the road, to gauge effectiveness of recovery actions now.

Active support from collaborators within and across jurisdictions has been integral to the Alberta recovery program. The diversity and sharing of perspectives and resources has been invaluable to standardize methodology, improve data col-

Table 1. Goal, objectives, and strategy of Alberta's whitebark and limber pine recovery plan.

Goal	Objective	Strategy
To have at least one self-sustaining metapopulation per species and per management unit, of sufficient size, composition, and distribution to sustain Clark's nutcracker populations within the historical range of whitebark and limber pine and support adaptation in their projected future range	1. By 2100, the rate of increase in the metapopulation of five-needle pine trees with elevated disease tolerance or resistance in each management unit is greater than the rate of decline caused by blister rust 2. By 2120, at least one self-sustaining metapopulation of each five-needle pine species is established north and south of Highway 1.	1. Maximize the frequency of disease-resistant trees in five-needle pine habitat in order to reverse the decline caused by white pine blister rust, supported by: 1.1. Identify, protect and test plus trees (i.e., trees selected in the field for disease resistance). 1.2. Develop at least one seed orchard for each species sufficient to supply seed with increased disease resistance to meet restoration needs. 1.3: Restore populations in suitable habitat to sustain ecological function. 2. Restore fire regime in five-needle pine habitat within the historical range of variability. 3. Address priority knowledge gaps.

lection, share information, leverage resources, fill knowledge gaps, access sites and materials, and build support. A list of key partners by category is below.

- B.C.: Ministry of Forests, Lands and Natural Resource Operations and Rural Development, B.C. Parks
- Canada: Parks Canada Agency, Natural Resources Canada—Canadian Forest Service Pacific, Northern, Laurentian, and Atlantic Forestry Centres
- U.S.: U.S. Department of Agriculture, Forest Service: Dorena Genetic Resource Center, Coeur D'Alene Forest Nursery, Rocky Mountain Research Station, Intermountain Research Station
- Academia: The King's University (Edmonton), Montana State University, University of Alberta, University of British Columbia, University of Calgary, University of Northern British Columbia, University of Victoria
- Non-governmental organizations: Whitebark Pine Ecosystem Foundation of Canada, Crown Managers Partnership High Five Working Group, Nature Conservancy of Canada
- Many private landowners whose property contains limber pine stands and plus trees (defined below)

RECOVERY ACCOMPLISHMENTS

Short-term and long-term actions must occur simultaneously. Sequential actions are guided by the Conservation Standards "results chains". Specific actions appropriate to each area or suite of habitat characteristics depend on the condition and status of the site, stand or population. Progress in each area is summarized below.

Improved Spatial Habitat Models

Development impacts to these species can be avoided or more effectively mitigated with accurate spatial data, such as timber harvest, linear project or ski area establishment. Provincial forest inventory (Alberta Vegetation Inventory) has poor accuracy for whitebark and limber pine, as design and sampling focus on commercial forest types. Where the two species overlap, site visits are required to confirm identification due to their similar appearance.

Spatial habitat suitability models were developed adapting McDermid and Smith (2008) for limber and whitebark pine in Alberta (excluding National Parks which had a similar project underway). Digital elevation models (DEM) at 25 m resolution were used in the few townships lacking LiDAR at 1 m resolution. A randomized training data set of presence and absence points and polygons was used to build the model, and one third of the data were reserved for validation. High and moderate whitebark pine habitat suitability classes and one suitable class for limber pine were supported (table 2a,b).

Spatial habitat suitability models (LiDAR and DEM for each species) are available for public download through Alberta's Open Data web portal. While not perfect, the resulting models were a significant improvement over previous range maps and accuracy assessments by township support their use for interpretation at the stand or population scale, and not to predict the location of individual trees. Stochastic factors such as competition, soils, disturbance, and bird-mediated dispersal caused discrepancies between the actual and predicted niches. A due-diligence check based on available records, imagery and a field check is recommended before proceeding with plans or activities.

These models, as well as field location records, are incorporated in updated spatial layers for the Government of Alberta Wildlife Sensitivity Layers, which support the Landscape Analysis Tool that permit applicants are required to use to determine potential overlaps with species at risk habitat, dispositions, and other features that may require design and mitigation measures.

Density models were explored, assigning density surfaces to the habitat model to infer stem counts based on average tree crown dimensions, but results were not accurate enough to use. As more field data is collected, density models may be pursued in the future.

Long-Term Monitoring

A network of over 250 long-term monitoring plots is established throughout the Rocky Mountains of Alberta and B.C. Each whitebark and limber pine tree taller than 1.4 m is tagged and reassessed for health, growth, form, and damage. Living regeneration is tallied by health status. These data are critical to quantify growth, regeneration, health, and mortality status and trends for national and regional

Table 2a. Modelling parameters for whitebark pine habitat probability in Alberta. Columns indicate parameter combinations and values applicable to each suitability category.

Parameter	Values	Low (exclude)	Low (exclude)	Low (exclude)	Moderate	High	High	High
Slope	50-150%			+		+	+	+
Elevation	1750-2250 m		+	+	+	+	+	+
Aspect	112.5-270°				+	+		+
Topography	Ridge						+	+
Canopy height[a]	3-30 m	+	+	+	+	+	+	+

[a]LiDAR model only

Table 2b. Modelling parameters for limber pine habitat probability in Alberta. Columns indicate parameter combinations and values applicable for suitable habitat.

Parameter	Values	Suitable	Suitable	Suitable	Suitable	Suitable
Slope	30-150%			+	+	+
Elevation	1450-1800 m	+	+	+	+	+
Elevation	1450-1800 m		+	+	+	+
Aspect	212-270°		+	+		+
Topography	Ridge	+	+		+	+
Canopy height[a]	3-30 m	+	+	+	+	+

[a]LiDAR model only

reporting. Stand- and region-specific recovery actions are guided by the monitoring results. These plots help identify areas where infection is high to target plus tree selection. The data can also be used to identify areas where natural regeneration is lagging mortality rates and requires restoration planting. Trends over time highlight regional and ecological pressures, such as rate of increase in severity and extent of blister rust and mountain pine beetle, as well as abiotic stressors (Shepherd et al. 2018; Smith et al. 2008, 2013a,b). These plots are identified provincially as high-value natural resources for wildfire protection, and to incorporate in planning and permitting.

Plots were established in the mid-1990s, with agencies gradually adding more. Starting in 2003-04, Parks Canada and Alberta worked to standardize all plots following published methodology by the Whitebark Pine Ecosystem Foundation (Tomback et al. 2005). The network of plots is remeasured every five years. Staff from different agencies now train together, co-ordinate planning, and share resources to ensure efficient and consistent data collection. Many sites require long hikes, helicopter access, or landowner permission to access. New plots are established to fill spatial and ecological gaps, and where mortality is extreme and access is lost, some plots are dropped (table 3).

Table 3. Current status of long-term monitoring plots.

Plots	Whitebark pine	Limber pine	Total
2019 assessed	80	164	244
Total plots	95	205	300

Plus Trees

Plus trees are trees that appear phenotypically disease-resistant in the field based on standardized assessment methodology (long-term monitoring plots or 100-tree survey temporary plots), but have not yet been tested to confirm heritable resistance. Priority stands have blister rust infecting at least 75%, ideally over 85% of pines. Trees exhibiting signs of resistance, or that are substantially healthier than the surrounding stand, that may not be symptom-free, are plus tree candidates (Mahalovich and Dickerson 2004). Field teams may assess hundreds of trees before selecting one plus tree. To ensure genetic diversity is maximized by not sampling from related groups of trees, plus trees cannot be less than 50 m apart.

The entire crown and stem of each plus tree is carefully evaluated for signs of blister rust with binoculars, ideally by two observers. Trees should be reproductively mature so seed can be collected for resistance testing. Scions (branch tip cuttings from upper branches) can be collected and grafted onto rootstock to develop a genetic archive with copies of the tree. Each plus tree receives a permanent metal tag with a unique ID, and is geolocated, measured and photographed. All information is stored in the provincial recovery program database and spatial layers, updated annually, and shared with land managers as these trees represent valuable and irreplaceable genetic resources. Plus trees determined to be at elevated risk of beetle attack annually are identified for protection by applying verbenone and green-leaf volatiles. This protection must be applied before beetles overwintering in the bark emerge, typically mid- to late June in these habitats.

Collections of seed before 2015 were based primarily on accessibility and area representation, yielding a broad sample of genotypes for conservation that were not selected for

Table 4. Plus trees selected for the Alberta recovery program.

Year	Selected limber pine	Selected whitebark pine	Monitored limber pine	Monitored whitebark pine
Pre-2015	0	0	0	0
2015	84	0	0	0
2016	51	47	0	0
2017	82	12	0	0
2018	2	0	163	24
2019	0	0	0	0
2020	0	0	145	28
2021	0	0	131	40

health. While 138 trees could not be confidently relocated, 383 were, but few met plus tree criteria. From 2015 onwards, field surveys focused on finding new plus trees and monitoring those in the program (table 4). Not all plus trees have been submitted for testing yet, or grafted in clone banks or seed orchards because of limited cone collection opportunities and funding. Because screening takes 7 years from when seed is submitted, no elite trees are identified yet, and plus trees are the source of all restoration seedlings.

Protection of Plus Trees from Mountain Pine Beetle

Annual overwinter survival surveys by Alberta forest health staff are used to identify areas with elevated mountain pine beetle pressure overlapping whitebark and limber pine habitat. High-value program components including plus trees are selected for protection from mountain pine beetle attack. A combination of verbenone and green-leaf volatiles in flaked packets is applied before beetle emergence, typically mid- to late-June. Studies have shown this treatment's high efficacy for whitebark pine (Cardinal et al. 2021), and it appears to be effective for limber pine as no treated plus trees have suffered fatal attacks to date. Where feasible, this is combined with other operational field work for efficiency.

Seed Collections

Seed collections are archived for long-term genetic conservation; used for scientific research; grown into seedlings for operational restoration planting; and exchanged with other agencies to support mutual goals. The seed inventory of the province is adjusted as seeds are withdrawn for use, and added to following collection and processing. Each tree, and each collection year, are tracked individually as the genetics differ because differing pollen contributions affects the genetics of the seedlot.

Collecting seed from these species is logistically challenging and very costly. Limber and whitebark pine produce moderate to heavy cone crops irregularly every three to five years (masting), with little intermittent seed. Cone crops can be assessed the previous year when they are immature, which helps with planning and securing resources. Seed needs to be collected as late as possible for the highest viability. To prevent wildlife predation from plus trees, protective wire mesh cages must be installed over cones early in the season, and removed in late fall. Cones grow only at branch tips, and each tree must be accessed and climbed twice. Cones require careful handling and time-consuming manual processing to extract and clean seeds, especially if there is a need to keep single tree seed separate, for example to test for disease resistance. Documenting properties for each parent tree and seed accession is key to tracking collections in the provincial archive at the Alberta Tree Improvement and Seed Centre in Smoky Lake.

Mast years occurred in 2010, 2015, and 2018 in Alberta, with a moderate cone year for limber pine in 2021. Collections before 2015 targeted geographic representation and accessibility, and included some collections where different trees were bulked (mixed) together (table 5).

Disease Resistance Screening

After the parent tree is selected, seeds are collected to produce seedlings that are then infected and screened to quantify the heritability of each parent tree's rust resistance, based on the performance of their offspring. Depending on the facility, the proportion and sometimes the type of resistance to blister rust that they pass on to their offspring can be characterized. Many plus trees lack heritable resistance, emphasizing the critical importance of testing to avoid continuing to use those trees for restoration, as their seedlings are likely to die from infection before they reproduce. Partly because not all plus trees have resistance, and partly because much of the resistance identified is only partial, many plus trees must be selected to deliver long-term resistance targets. Some plus trees with elevated partial resistance will still get infected and die, and only a proportion of seedlings from partially resistant parents will survive. No whitebark pine and only a small fraction of selected limber pine parent trees have complete resistance, conferred by a single dominant gene (Sniezko et al., in press). While highly valuable, this single gene is likely to be overcome by the pathogen evolving virulence, so layering multiple types of resistance is the strategy that will lead to the most widespread, durable resistance, rather than deploying the same single-gene resistance as broadly as possible. The baseline wild population level of blister rust resistance is zero (fully susceptible). Trees with a certain threshold of heritable resistance after testing are "elite" trees.

Screening takes seven years from seed (once stands are surveyed, plus trees identified, and a year with a collectible cone crop occurs). A two-year-old seedling has enough foliage to inoculate for reliable results. A garden of inoculum sources on the main alternate blister rust host (Ribes spp.) is maintained and from 25 to 144 seedlings per plus tree (varying with each program) are randomly assigned to blocks. When spores are at the appropriate stage to infect

Table 5. Seed collections at Alberta Tree Improvement and Seed Centre.

Collection year	Whitebark pine number	Whitebark pine kg	Limber pine number	Limber pine kg
Pre-2015	391,224	35.200	904,485	70.677
2015	12,706	1.626	135,208	10.779
2016	61,954	6.720	907	0.078
2017	1,598	0.273	8,365	0.773
2018	62,067	7.506	208,779	14.305
2019	0	0.000	0	0.000
2020	0	0.000	9,967	0.821
2021	18,208	2.276	72,672	6.056

pine needles, seedlings are inoculated under carefully controlled conditions so they are fully infected at high concentrations, but not overwhelmed with unrealistic concentrations, of spores. They are then monitored over four years as the different resistance mechanisms develop over time, ultimately yielding a score for the parent tree.

Several facilities have developed blister rust resistance screening capacity. The U.S. Forest Service has dedicated facilities at Coeur D'Alene Forest Nursery in Idaho (CDA) and at the Dorena Genetic Resource Centre in Cottage Grove, Oregon (DGRC). The B.C. Ministry of Forests, Lands and Natural Resource Operations and Rural Development has developed Canada's first screening facility at Kalamalka Forestry Centre in Vernon (KFC). Table 6 shows the material Alberta has sent for screening. Occasionally trees needed repeat screening as a result of various factors including poor seedling production or low inoculum concentrations, so the numbers of trees may total more than the numbers of plus trees screened. Agency collaborators have also screened parent trees for other recovery partners, such as National Parks and B.C. Parks, which are not included in these tallies, but would contribute to the material included in seed orchards if they meet the guidelines for planting in Alberta.

Table 6. Trees sent for disease-resistance screening, by sowing year.

Year	Whitebark pine	Limber pine
2010	10* CDA	0
2015	6 KFC	50 DGRC
2016	8 KFC	50 DGRC
2017	7 FKC	50 DGRC
2018	9 KFC	12 DGRC
2019	10 KFC	6 KFC
2020	0	0
2021	0	0

Restoration Planting

Planting seedlings is what restoration typically brings to mind, which represents the culmination of many of the prior and subsequent steps described here. Years of advance planning are needed to grow durable seedlings and secure authorization to plant in a suitable site. These valuable seeds must be stratified with a series of controlled moisture and temperature treatments for five to six months to ensure all potentially viable seeds germinate consistently. A two-year-old whitebark pine seedling with robust roots has the optimal balance between performance, cost, and time compared to younger seedlings, or seeds, which have very high predation rates. Working with nurseries is important to build capacity and improve results over time to grow whitebark and limber pine seedlings at an operational scale. A multi-year learning curve is needed compared to growing commercial reforestation seedlings. These significant costs mean that Alberta is focused on propagating plus tree seeds to maximize long-term survival to achieve recovery goals.

Regulatory requirements in Alberta specify a seedlot must be registered with the province before it can be planted on Crown land. All limber and whitebark pine seedlots have been registered, and have dispositions established identifying restoration projects on provincial land.

Tens of thousands of seedlings need to be grown and planted annually for significant progress in recovery. By building a program over time, planting numbers have shown an increasing trend (table 7).

Table 7. Plus tree and elite (screened) seedlings planted and hectares restored in Alberta.

Year	Whitebark pine seedlings	Whitebark pine hectares	Limber pine seedlings	Limber pine hectares
2018	1700	6.80	550[a]	5.50
2019	0	0.00	7227	36.00
2020	4400	13.28	1600	10.21
2021	200[b]	0.50	6976	12.23

[a]another 550 were planted in Waterton Lakes National Park
[b]planted in Waterton Lakes National Park

Seed Zones and Provenance Trials

To ensure that seedlings are suited to the environment where they will grow for the next century or more, their ranges in Alberta are divided into species-specific seed zones reflecting adaptation and regional differentiation. Based on long-term provenance trial results, the zones and transfer limits may be adjusted over time. Provenance trials, also called common garden studies, are long-term tests that compare performance of genotypes sourced from different areas when growing in a common environment. Provenance trials quantify how far seed can be moved (geographically or climatically) from its origin location before it becomes maladapted. A genetically diverse and well-adapted population is needed for restoration in each region. This may be challenging in regions where rust infection levels are too low to select plus trees, and alternate strategies may be more appropriate.

Alberta has one limber pine provenance trial, planted in 2016 with three-year-old seedlings that tests 145 seed sources from 30 populations sampled along the Rocky Mountains. A paired test site is at Fort Collins, Colorado, comprising the International Limber Pine Provenance Study (ILPPS) in partnership with the U.S. Forest Service Southwest Research Station and the University of B.C. Faculty of Botany. Age 5 measurements (planted; age 8 from seed) for growth and vigour were completed in 2021. Alberta also has one test site of a series of 12 whitebark pine provenance trials, plus some smaller ancillary tests that were established by the B.C. Ministry of Forests, Lands and Natural Resource Operations and Rural Development in 2015 and 2017. The Alberta site was planted with two-year-old seedlings in 2017 with 52 range-wide sources.

Seed Orchards

A seed orchard is a plantation containing copies (clonal orchard) or progeny (seedling orchard) of selected trees that is designed to maximize seed production in a single location. Seed orchards composed of the best available material will expedite whitebark and limber pine recovery. Grafted orchards are being established containing copies of the best selected or tested trees, which will be pollinated by a diverse group of the other best trees for each seed zone. As test results become available, poor performers can be removed (rogued) and new plus tree selections, or more copies of tested elite trees, can be added. Multiple seed orchards can be co-located in a single area to facilitate administration and management, especially for these species that appear to have broad transferability. A seed orchard can be outside the seed zone and ideally far from potentially contaminating pollen sources, as long as the location supports good pollen and seed production. Because these are the first seed orchards of these species and our knowledge of their reproductive biology off-site is lacking, partners agree the best approach is to establish multiple sites in several different environments.

Following a workshop among partners, a range of key topics were discussed and several have been finalized, including candidate sites, delineation of seed zones, partner contributions, and policy options and alignment to yield outcomes consistent with provincial regulatory requirements for seed orchards and seed transfer. Because Alberta contains around 90% of the Canadian range of limber pine, one orchard is established in Waterton Lakes National Park with a second candidate site planned for establishment trials in 2022 on property owned by the Calgary Zoological Society. At least two seed orchards are established for whitebark pine in B.C. The lifespan of these orchards is expected to be at least 50 years, so the right size, design, location, infrastructure, management input, and access decisions are very important.

Clone banks are key complements to seed orchards as ex situ living genetic archives. They contain copies of selected material as a backup in case the original parent tree is killed or can no longer be accessed. Clone banks can also be used for tree breeding as they mature. There are at least two whitebark pine clone banks planned or established in B.C., and plans are being developed for limber pine clone banks.

Knowledge gaps around the reproductive biology of whitebark and limber pine are being addressed through a literature review, and establishing various pilot studies including cone induction methods, different site ecology for multiple orchards, and orchard management options that will include irrigation, fertilization, and pollen management.

Habitat Thresholds

Studies have indicated that a threshold of cone-producing whitebark pine is needed to sustain Clark's nutcracker visitation (Barringer et al. 2012; McKinney et al. 2009). Because it is impractical to count cones or infer cone density over broad areas, substitutes such as stem counts or basal area per hectare of mature trees can be used. After piloting several options, Alberta has been collecting basal area with variable radius prism plots. This data can help characterize stands that are likely producing sufficient cones to consistently reproduce at the upper bound of basal area, and those that are marginal or need planting at the lower bound of basal area.

A key data gap, however, is whether these thresholds, based on stands in the Yellowstone region, correspond with ecosystems in Canada where key factors such as stand composition and Clark's nutcracker alternate food source availability differ substantially. Systematic bird telemetry studies in Canadian habitats are needed to fill this gap.

Other Restoration Projects

Optimizing seed handling and germination of whitebark and limber pine

Consistent with what other practitioners have observed, Robb (2020) found that collecting cones later promotes embryo and seed development. This effectively mimics nature: Clark's nutcrackers cache seeds underground, where they overwinter and continue developing, often germinating the following spring or even the year or two after. A complex and long seed stratification process yielded the best germination results. A well-drained growing medium was also important to sustain even temperatures and minimize bacterial and fungal damage. Other practitioners have found removing empty seeds by weight also reduces bacterial and fungal contamination caused by empty seeds decaying in stratification.

Thinning competing species to release whitebark pine

In 2017, a replicated, controlled thinning study was conducted in cutblocks in southwestern Alberta to determine the most effective competition release treatment for slow-growing whitebark pine. Blocks were harvested in the mid-1990s, scarified and regenerated mostly to lodgepole pine, but with substantial amounts of natural whitebark pine. Thinning distances, repeated in four cutblocks, were 0, 2, and 5 m radius from whitebark pine, retaining a fully stocked stand of commercial species. Data were collected on overstorey and regeneration tree species and sizes, as well as health of whitebark pines, which were all tagged. Each of the 12 plots is established as a provincial Permanent Sample Plot to facilitate remeasurement. There may be the opportunity to replicate this trial in other areas. An operational project of another 28 hectares in the same area thinned 5 m around whitebark pines.

Fire history, regeneration and health of whitebark and limber pine stands

In 2019 a project to study relationships between fire history and regeneration was conducted in the Canadian Rocky Mountains to systematically investigate anecdotal reports and regional studies suggesting whitebark and limber pine regeneration in Canada is less fire-dependent than in the U.S., possibly related to cooler, snowy conditions. A streamlined assessment of fire history evidence and categorical assessments of ground fuels and fuel types was done in nearly 250 stands planned for long-term repeat monitoring where time and resources permitted. Assessment methods may have underestimated fire evidence, especially for low severity burns because this was not a dendrochronological study. Old burns (over 20 years prior) could have been more prevalent, but recent burns (within 20 years) aligned well with available data sets.

Neither whitebark nor limber pine showed any trends in regeneration density with latitude or elevation. There was a weak relationship between regeneration density and live tree density within stands for limber pine but not for whitebark pine. Whitebark pine had higher regeneration densities than limber pine. There were no differences for health or regeneration density between burnt and unburnt sites overall. Recently burnt whitebark pine sites had higher blister rust infection rates, reflecting the increase in understorey vegetation. Unburnt sites had significantly higher whitebark pine regeneration density than sites with old burns, but only slightly less than recent burns. About half the stands of each species with regeneration had no evidence of fire, implying that fire is not essential for regeneration or recruitment in the Rocky Mountains in Canada.

Mycorrhizal effects on seedlings

In 2016, two species of Suillus mycorrhizal fungi were collected for Dr. Roland Treu of Athabasca University to inoculate whitebark pine seedlings, which improves seedling nursery growth and survival by 10 to 15%. However, no significant differences have been found in field performance following inoculation (Cripps et al. 2018). There is potential to continue this work should resources permit. Forest nurseries can operationally inoculate seedlings by applying a slurry of mycorrhizae through irrigation booms.

Charcoal/biochar effects on regeneration

In 2017, samples were collected from the upper 10 cm of soil in a burnt whitebark pine stand near Landslide Lake to support a project at University of Alberta characterizing biochemical aspects of mycorrhizal and soil characteristics in these types of stands.

DATA MANAGEMENT, INFORMATION SHARING, AND EXTENSION

Sharing and promoting knowledge spurs momentum for recovery of endangered species and ecosystems by helping the public, stakeholders, and policymakers understand their importance and the challenges that they face. Supplementary information ensures funding agencies are aware of realistic costs, limitations and timelines related to project deliverables. The slow growth and maturation of these species poses a special challenge. Most people find it hard to grasp the long consequences of impacts, and the long recovery horizon. The time scales are a poor fit for agency tracking and reporting. A seed collected now, grown into a seedling, planted and growing to maturity in its habitat, will not start to produce its own seeds for about 80 years: that is one single tree generation.

Whitebark and limber pine are well-represented in protected areas and only somewhat threatened by human impacts outside of parks, which is quite a different scenario than for most species at risk. Only active restoration measures focusing on disease resistance will ensure their long-range persistence in numbers sufficient to keep Clark's nutcracker visiting stands and planting their seeds. The multifaceted recovery actions that culminate in planting a tree take nearly a decade, and all are equally important, but most supporting activities require special expertise or training, limiting opportunities for direct public participation.

A dedicated email to reach the recovery team co-chairs, and included in current extension resources, is goa.endangeredpine@gov.ab.ca.

Data Collection

Spatial data consolidation and sharing

Locations of monitoring transects, plus trees, and restoration project areas are consolidated in the provincial Layer Manager spatial dataset, available internally to staff. Data are also submitted annually to Alberta Wildfire to identify these high value elements for fire management planning. Data is also shared with Agriculture & Forestry, Alberta Environment and Parks, Parks Canada, the U.S. Forest Service, and the Crown Managers Partnership, as well as researchers upon request. This data has also been used to support land use and resource management planning for the Castle parks management planning; implementation of the South Saskatchewan Regional Plan under the provincial Land Use Framework; forest management planning and identification of species at risk to improve forest inventory, management and operational plans; and research projects at University of Alberta, University of Northern British Columbia, and Athabasca University.

Citizen science app

In 2016 the provincial spatial analyst built a free citizen science app "Save the Pine" created in ESRI's Survey123 for recreational users and volunteers to collect location and basic access and health data on 5-needle pines. Data collected can be cached and submitted to the provincial recovery team after returning to cellular or wifi signal. However, uptake has been low and there is now better participation with individuals submitting iNaturalist records.

Plus tree and stand data collection app

Provincial staff have been using the ESRI Collector app to collect field data on mobile devices. This significantly reduced project data management time and errors, compared to non-digital options. Data were collected against background imagery linked to polygons (stands), points (trees), and other features, and backed up and managed remotely to a secure online data management hub (ArcGIS Online) after syncing to a wireless connection. Multiple crews can collect data simultaneously for the same project. Data can be exported and managed in various formats and security settings for tiered team access.

Public presentations

Invited and submitted presentations on Alberta's whitebark and limber pine recovery program have been delivered at numerous workshops, community of practice forums, academic lectures, and conferences. The theme and audience are considered carefully when developing each presentation. Hosts have included the Alberta Invasive Species Council, Alberta Native Plant Council, Alberta Forest Management Branch as well as Forest Health and Adaptation staff, Junior Forest Rangers field days, Crown Managers Partnership, seed orchard partners, provincial government spatial data community of practice, University of Alberta public lectures as well as graduate and undergraduate lectures, the general public, and naturalist groups. Specialist presentations at conferences and workshops are described in the Publications section.

Landowner, proponent, and tenure holder outreach

Alberta has engaged landowners and tenure holders by sharing information, extension materials, and results related to the trees on and near their property in conjunction with access permission requests and project referrals. All landowners and leaseholders approached to date are concerned about the status of endangered pine trees and support conservation and restoration measures, often granting access to additional areas for surveys and restoration opportunities.

Responses to project referrals overlapping or near pine habitat often spur positive engagement as proponents aim to avoid and minimize impacts, and mitigate impacts that may be unavoidable. Such projects include mining and quarry projects, powerlines, recreational facilities, expansions of existing sites, and oil and gas infrastructure. Proponents receive information to support best practices, and detailed information on plus trees and other irreplaceable installations like monitoring transects when appropriate. This has raised awareness, encouraged more proactive measures during project planning and construction, and enhanced sharing of monitoring and related data.

Locations of plus trees and habitat models have also been shared with forest tenure holders to improve outcomes for limber and whitebark pine in forest management planning and operations. Updated forest inventories incorporating this data have been used to more accurately delineate stands with unmerchantable endangered pines and remove those stands from operable areas, proactively minimizing potential impacts. Some tenure holders intend to collect location records of these species, strive to retain healthy trees in unhealthy stands, and avoid impacts to irreplaceable recovery assets such as plus trees and monitoring plots.

Indigenous community outreach

Several Alberta Indigenous Nations have reserve lands and traditional territories that overlap limber, and to a lesser extent, whitebark pine stands. After receiving permission, field crews have surveyed stands and selected plus trees there, and invited members of First Nations to join field surveys. Information is periodically shared about the recovery program, and seedlings have been provided. Work to build better connections and strengthen relationships is ongoing throughout the range of these species in Alberta.

Web extension

The recovery program is summarized in the provincial website, and includes a more detailed annual summary update available for download directly or through Open Data. https://www.alberta.ca/whitebark-and-limber-pine-recovery.aspx. Accessed January 26 2022.

A whitebark pine ESRI Story Map "Living on the Edge" was published highlighting the recovery program background and achievements. https://esrd.maps.arcgis.com/apps/Cascade/index.html?appid=d69f30908553449baef93beb7f7689e7. Accessed January 26 2022.

A poster was presented at the 2021 Crown of the Continent Forum on Fire in the Crown: https://www.crownmanagers.org/s/CMP_Poster2.pdf. Accessed January 26 2022.

An article was published on planting seedlings with Nature Conservancy of Canada volunteers: https://www.e-know.ca/regions/east-kootenay/volunteers-plant-endangered-trees-in-crowsnest-pass/?fbclid=IwAR0jiPIwbjvQiR5DuXtbmrFrPFWd9FMQVS-QuA6AUXHUKoqIhs-gsvWxbxc. Accessed January 26 2022.

An article on restoration planting was posted on the Whitebark Pine Ecosystem Foundation website and newsletter: https://whitebarkfound.org/slowly-but-surely-for-albertas-whitebark-and-limber-pine/. Accessed January 26 2022.

Alberta Environment and Parks has since archived a short 2016 blog on the recovery program.

Training

Field training is essential to collect accurate and consistent data, rigorously select plus trees, and safely collect high-quality cones and scion. At the beginning of each field season, field crews from multiple agencies cross-train together in the field to benefit from detailed hands-on field training sessions facilitated by agency experts to learn how to identify forest health issues and collect consistent, high-quality data for Parks Canada, Alberta and other partners. Training sessions specific to addressing the unique challenges of whitebark and limber pine cone collection have been developed and hosted by ArborCanada and Parks Canada, including a train-the-trainer module in 2019. These climbing and access methods have been adopted as agency Standard Operating Procedures and by the Forestry Division Occupational Health and Safety program. Field volunteers, as well as staff from other agencies and NGOs, have also been trained in the past on a case-by-case basis. In future years, training for NGOs is anticipated to support broadening capacity and empowering conservation landowners to support the program on their own conservation properties.

Publications

In 2015 updated whitebark and limber pine Alberta Species At Risk program brochures, bookmarks, stickers and magnets were produced, as well as interpretive all-weather signs in three sizes highlighting limber and whitebark pine recovery work. Signs were distributed to AEP staff to post at trailheads, along trails and at staging areas near limber and whitebark pine stands. Brochures are available electronically through the AEP Species at Risk and Government of Alberta Open Data websites, and hard copies of these materials are available upon request and provided to various offices for distribution.

Publicly accessible short articles on Alberta's recovery program have been published in Nutcracker Notes, the twice-annual publication of the Whitebark Pine Ecosystem Foundation (e.g., Krakowski 2020), which receives citations in peer-reviewed publications. Bugs & Diseases, the Alberta Forestry Division Forest Health and Adaptation newsletter published three times annually, has carried regular program and project updates. Articles describing program developments have been published in the twice-annual Tree Seed Working Group Bulletin, published by the Canadian Forest Genetics Association (Krakowski 2017, 2018, 2019).

Best practices for working with these species in Alberta are available upon request from the provincial recovery team and posted on the website of the Whitebark Pine Ecosystem Foundation of Canada. Agencies such as the High-Five Working Group of the Crown Managers Partnership, Whitebark Pine Ecosystem Foundation (Tomback et al. 2022), the Province of B.C. (Moody and Pigott 2021; Pigott et al. 2017), and Parks Canada also have developed guidelines tailored to those regions.

A summary of the provincial five-needle pine program was published in the proceedings of the 2016 international conference Forest Gene Conservation: Banking on the Future. The whitebark and limber pine habitat suitability modelling was published in the 2017 proceedings of the joint Canadian and Western Forest Genetics Associations. The Alberta limber pine program disease resistance screening for major gene resistance and multigenic resistance is published in the 2018 proceedings of the 6th International Workshop on the Genetics of Tree-Parasite Interactions: Tree Resistance to Insects and Diseases: Putting Promise into Practice (Sniezko et al. 2020), and an update is in press in the proceedings of the International Union of Forest Research Organizations (IUFRO) conference of working groups on pine stem rusts and genetics of five-needle pines (Krakowski, in press). A summary of the study on fire and regeneration was presented at the 2021 Crown Managers Partnership Forum on Fire in the Crown of the Continent (Krakowski et al. 2021). Genomics applications and tools related to major gene resistance identified in Alberta limber pine and potential applications in recovery have been published in journals (Liu et al. 2020; Sniezko et al. 2016) and presented at several conferences including the above IUFRO meeting (Sniezko et al. 2019) and the 2021 High Five II conference on high-elevation five-needle pines (Sniezko et al. 2021) where several other papers and posters relevant to the Alberta recovery program were presented. Alberta has contributed material and data for numerous other publications on the genetics and general status and recovery outlook of these species.

FUTURE DIRECTION

Because of the irregular cone crops and the labour-intensive and specialized demands of seed collection, multiple years of planning. Regular activities include: monitoring plus tree health status, collecting stand basal area and/or density data to improve characterization of stand density and delineation of critical habitat as defined in the federal recovery strategy, protecting at-risk plus trees from mountain pine beetle, identifying new plus trees, collecting scions for gene conservation in seed orchard and/or clone bank locations, keeping a continuous supply in production of seedlings to plant, and matching sites with appropriate restoration activities.

The five-year long-term monitoring program remeasurement next occurs in 2024. Given the major workload, other activities, besides fall planting, may not occur.

Based on ongoing tracking and monitoring results and new research, the recovery plan and supporting elements including seed zones and seed transfer rules may be revised from time to time to maximize program effectiveness and incorporate new knowledge. The spatial and temporal scope of the recovery program for these species means that a long term, dedicated effort among partners is essential for success.

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