

Final project report

Alberta Innovates Project 222302086

High Five: Adapting spatial tools to restore and promote biodiversity in endangered pine ecosystems in Alberta's Rocky Mountains and Foothills



PREPARED FOR: DR DALLAS JOHNSON, DIRECTOR, LAND AND BIODIVERSITY AT
ALBERTA INNOVATES

PREPARED BY: JODIE KRAKOWSKI, WPEFC

APRIL 2026



Environment and
Climate Change Canada

Environnement et
Changement climatique Canada

Acknowledgement of major project partners: Alberta Innovates, Parks Canada Agency, Environment and Climate Change Canada Environmental Damages Fund.

Disclaimer

Alberta Innovates (AI) and His Majesty the King in right of Alberta make no warranty, express or implied, nor assume any legal liability or responsibility for the accuracy, completeness, or usefulness of any information contained in this publication, nor that use thereof infringe on privately owned rights. The views and opinions of the author expressed herein do not necessarily reflect those of AI or His Majesty the King in right of Alberta. The directors, officers, employees, agents and consultants of AI and the Government of Alberta are exempted, excluded and absolved from all liability for damage or injury, howsoever caused, to any person in connection with or arising out of the use by that person for any purpose of this publication or its contents.

Contents

Executive summary.....	1
Introduction	3
Subject - data-driven whitebark and limber pine ecosystem recovery	3
Knowledge and technology gaps addressed by this project.....	4
Knowledge and technology description	4
Project performance metrics	5
Methodology	5
Project Results.....	9
Milestone 1 Complete CCE 5NP model validation and 5-year Spatial AB 5NP Restoration Plan..	9
Milestone 2 Draft Rockies and Foothills Spatial 5NP Restoration Plan.....	10
Milestone 3 Validate and complete Rockies and Foothills Spatial 5NP Spatial Restoration Implementation Plan.....	10
Milestone 4 Implement & Monitor Restoration Treatments.....	11
Clean Resources Metrics	11
GHG Emissions Reduction Metrics	14
Project Success Metrics.....	14
Results summary	14
Overview – 2025 restoration activities	15
Monitoring Prior Planting	24
Conclusions / Key Learnings.....	26
Key learnings and importance.....	26
Filling knowledge gaps with project results.....	27
Broader interest and applicability	27
Authorizations.....	27
Outcomes and Impacts	28
Publications and presentations	28
Benefits	29
Economic	29
Environmental	29
Social	30
Building innovation capacity	30
Recommendations and Next Steps.....	30
Long term plan.....	30
Partner engagement.....	30

Follow up project: model refinement with additional data	31
Follow up project: data hub	31
Knowledge Dissemination.....	31

Figures

Figure 1. A successful limber pine seedling planted in 2024, protected from insolation and wind desiccation by a sheltered microsite (shrub), assessed in a long-term seedling plot.....iv	
Figure 2. Limber pine tree fatally infected with blister rust. As the infection progresses, the tree stops producing cones and dies.....	3
Figure 3. Clark's nutcracker, obligate seed disperser of whitebark pine and primary disperser of limber pine.	4
Figure 4. Steps to develop spatial restoration implementation tool kit and plan.	5
Figure 5. Expanded project area for spatial restoration plan model development, covering the full alberta ranges of both whitebark and limber pine.	6
Figure 6. Potential range of whitebark pine in the project area: green is 1.0 probability and red is 0.5 probability, white is >0.5 probability.	7
Figure 7. Potential range of limber pine in the project area: green is 1.0 probability and red is 0.5 probability, white is >0.5 probability. This model overpredicts limber pine and was later adjusted.	7
Figure 10. To prevent wildlife predation, cones from disease-resistant trees must be protected with wire mesh cages early in the season, and removed when cones are collected in fall when the seeds are ripe.	11
Figure 11. Overview of 2023, 2024 and 2025 planted and monitored sites in alberta. Yellow is limber pine, pink is whitebark pine – polygon sizes are buffered to improve visibility. Blue is 12x12 km landscape grid squares to support connectivity planning developed for the spatial restoration tool kit.....	13
Figure 12. Overview of 2025 planted sites. Yellow is limber pine, pink is whitebark pine – polygon sizes are buffered for visibility. Grid is 12x12 km landscape grid squares developed for the spatial restoration tool kit.....	16
Figure 13. Vigorous, multi-stemmed whitebark pine seedling planted in a protective microsite in a monitoring plot.	16
Figure 14. Sugarloaf whitebark pine planting site. Pink is the planted area, green outlines the potential restoration polygon, which includes a wildfire lookout tower. Blue is the 12x12 km grid square boundary.	17
Figure 15. Seedling cache in a whitebark krummholz clump.....	18
Figure 16. Quad squad volunteers each planted a seedling.....	18
Figure 17. Prairie bluff whitebark pine planting site (upper) and monitoring plot area (lower). Pink is the planted area, green outlines the potential restoration polygon.	18
Figure 18. Crew fist bumps after completing another monitoring plot in 80 km winds	19
Figure 19. Keeping a straight transect is essential to relocate the seedlings	19
Figure 20. Zoratti ranch limber pine planting site and monitoring (easternmost area), green outlines the potential restoration polygon.	20
Figure 21. Mature limber pine trees and native fescue ecosystem on the property.....	20
Figure 22. Planted seedling in a shrub microsite.....	20
Figure 23. Honeymoon creek limber pine planting site and monitoring plots (lower central square shape), green outlines the potential restoration polygon.	21

Figure 24. Honeymoon site and upper oldman river. 22

Figure 25. Planting in kinnickinnick along a monitoring plot. 22

Figure 26. Ncc christie mines limber pine planting site..... 22

Figure 27. Planting site with sparse limber pine and protective logs and shrubs..... 23

Figure 28. Rocky ridge with sparse limber pine. 23

Figure 23. Limber pine seed orchard, waterton lakes national park. 23

Figure 26. Vigour of seedlings planted in 2024. 25

Figure 27. Vigour of seedlings planted in 2022. 26

Figure 28. Vigour of seedlings planted in 2020. 26

Figure 29. Goa forest health officer (now senior area forester) in the field helping wpefc collect
whitebark pine cones. 31

Tables

Table 1. Restoration seedling planting site summary for the project within alberta, by year. Sites in
italic font are innovative/atypical sites selected from model predictions in core polygons
with high likelihood of planting success. Excludes grafts and sites outside alberta. Survival
includes only confirmed living trees and not missing trees in plots. 12

Table 2. Restoration seedling planting in 2025 – sites selected based on model predictions and
ground truthing. Excludes grafts and sites outside alberta..... 13

Table 3. Prior planting monitoring sites (assessed 2025). Left is %, right is seedling numbers. 25



FIGURE 1. A SUCCESSFUL LIMBER PINE SEEDLING PLANTED IN 2024, PROTECTED FROM INSOLATION AND WIND DESICCATION BY A SHELTERED MICROSITE (SHRUB), ASSESSED IN A LONG-TERM SEEDLING PLOT.

Executive summary

The goal of this project was to support effective, data-driven endangered pine recovery across the Alberta and BC Rocky Mountains and Foothills. The resulting plans and data for Alberta supported by this project encompass 5.3 million hectares, greatly facilitating decision making and information sharing, and targeting the most impactful endangered pine recovery actions. We are confident that the deliverables and our multi-pronged outreach to promote awareness and support their application fulfills this goal and met the project objectives.

The objectives of this project were:

1. to adapt (Milestone 1) and expand (Milestones 2 & 3) pilot spatial models developed for endangered limber and whitebark pine to novel ecosystems;
2. to validate model predictive accuracy in diverse ecosystems and conditions (Milestone 3);
3. model implementation to support strategic and operational restoration of these unique ecosystems in Alberta and Canada to support biodiversity enhancement in degraded ecosystems (Milestone 4).

Key results include:

- expansion and adaptation of a spatial restoration modelling process to encompass the entire ranges of both endangered pine species throughout Alberta (Milestones 1 & 3);
- of development of consolidated spatial data layers and associated tool kit to support endangered whitebark and limber pine restoration in Alberta (along with all raw and cleaned data and coding developed for the project) (Milestones 2 & 3);
- application of those layers to craft a prioritized spatial restoration strategy with implementation guidance designed to lead to species recovery in Alberta (Milestone 3);
- extension to raise awareness of the plan and tool kit among subject matter experts, government regulators, practitioners involved in endangered pine recovery in Canada (Milestone 3);
- implementation of priority activities identified in the plan in both typical and novel habitats selected to maximize climate change resilience (Milestone 4);
- monitoring of implementation results to evaluate their effectiveness (Milestone 4).

Learnings from this project included:

- data availability and resolution for various attributes varies greatly among partners (e.g., forest inventory polygon data for Alberta vs. BC, data collected among individual national parks and other areas differs)
- limiting field data to Canadian sources created edge effects at jurisdictional boundaries
- adding range-wide data would improve model attribute accuracy for most layers, especially for limber pine which has a relatively small part of its range in Canada
- the degree of partner participation and review greatly influenced jurisdictional model output accuracy
- implementation workshops and written guidance were essential to ensure partners understand the layers and how to apply them to develop restoration implementation plans
- Incorporating additional local data sources and imagery to supplement the spatial tool kit is necessary to develop a robust restoration plan

- field (and/or aerial) validation was instrumental in improving model parameters (and where field validation was sparse or lacking, model outputs were less representative of field conditions)
- Field monitoring of treatments is key to inform future restoration decisions
- Restoration site attributes (ecology, topography, disturbance) and access varies greatly between jurisdictions
- Each jurisdiction has unique needs, priorities and constraints, requiring customized modelling, restoration plans and treatments for each region, while an overall general model is useful to support integrated decision making across jurisdictions
- This tool kit is focused on western science and data, supporting outcomes based on biological feasibility and ecological priority and treatment feasibility. Incorporating Indigenous and cultural values can be done by superimposing those attributes and locations on top of the model outputs to further refine plans.

Together with matching partner funding and engagement, this project supported the following outcomes:

- Restoring over 80 hectares of degraded whitebark and limber pine habitat by planting over 35,000 disease-resistant seedlings in identified priority sites
- Planting seedlings in 2 novel sites (cool aspects, shaded underplanting) and 19 typical sites (variable and warm aspects)
- Monitored average year 1 planted seedling success of 78%, with 92% in innovative sites and 67% in typical sites
- Province-wide spatial restoration implementation plan document and associated shapefiles submitted to GOA, partners, and available upon request
- About 500 recipients of information on the spatial restoration plan, data and development process from 1 article, 2 webinars, and numerous presentations
- Alberta authorizations for future multi-year plantings in sites identified in the restoration plan

Benefits of this project:

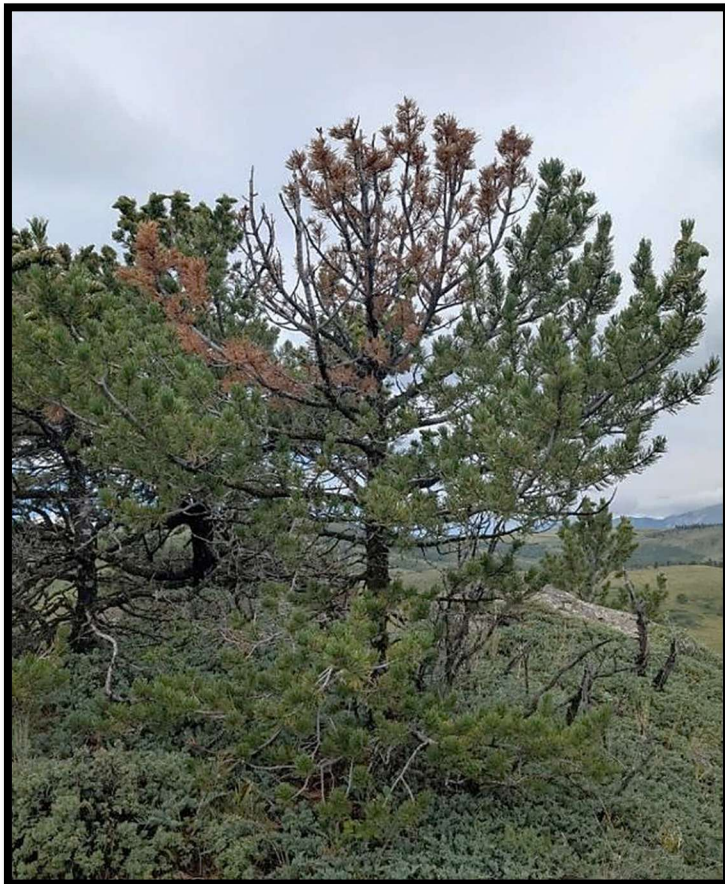
- Complete, spatially explicit plans with detailed implementation guidance to recover Alberta's endangered whitebark and limber pine ecosystems are complete and can be used to align and direct future restoration work among interested partners
- Newly updated and compiled spatial layers cover the Alberta ranges of these species and can be used to support land use planning and operations as well as restoration projects
- Canadian partners in recovery are using an aligned approach to systematically apply existing data to restoration plans
- The restoration plans explicitly incorporate current scientific approaches and benchmarks, including population distribution objectives aligned with recovery strategies and plans developed, or under development, in multiple jurisdictions
- The restoration plans can be used going forward to delineate specific area-based projects and facilitate permitting and working with partners across the landbase
- WPEFC hosts a large repository of current spatial data key to recovering these species in the eastern part of their Canadian ranges

Introduction

Subject - data-driven whitebark and limber pine ecosystem recovery

The Whitebark Pine Ecosystem Foundation of Canada (WPEFC) is a non-profit devoted to education, conservation, and restoration of Canada's endangered whitebark and limber pine ecosystems. Registered in BC in 2009 and in Alberta in 2020, WPEFC aims to connect partners across jurisdictions, share knowledge, and expedite recovery of these slow-growing keystone species. We have successfully restored thousands of hectares of habitat in Canada and managed complex multi-year projects. WPEFC collaborates with governments at all levels, Indigenous nations, non-profits, industry, individuals, and academia. WPEFC is the leading proponent of endangered pine restoration in Canada, and is currently the only organization implementing and tracking restoration treatments for these species in Alberta.

Whitebark and limber pine are endangered in Canada and in Alberta due to their rapid declines relative to their slow rates of recruitment. Both species are keystone species in Alberta's Rocky Mountains and Foothills, where these slow-growing trees can persist for over 1000 years. The main cause of mortality is the introduced fungal disease white pine blister rust that is fatal to all but a small proportion of trees that have natural genetic resistance (Fig. 2). Recovery in Alberta focuses on identifying, protecting and propagating rare genetically disease-resistant trees, increasing the frequency of disease resistance across the landscape. Other threats include mountain pine beetle, changes to fire regimes directly and indirectly impacting tree survival and site ecological suitability for recruitment, climate change interacting with the above factors as well as with competing species, and direct human impacts.



Recovery plans systematically address measures to mitigate these threats at a strategic level. Restoration plans provide operational guidance on what actions to take where and when to lead to successful outcomes. Spatial tools now available using species and habitat modelling approaches can support detailed spatially explicit restoration planning integrating a broad range of climatic, topographic, ecological, and operational factors that inform optimal actions for specific sites to achieve restoration targets.

FIGURE 2. LIMBER PINE TREE FATALY INFECTED WITH BLISTER RUST. AS THE INFECTION PROGRESSES, THE TREE STOPS PRODUCING CONES AND DIES.

Seeds of both whitebark and limber pine are large and nutrient-dense, prized by wildlife. Since these species rely on Clark's nutcracker for seed dispersal (Fig. 3), landscape scale planning takes their dispersal behaviour into account to ensure connectivity for gene flow of both seeds and pollen. Recovery must integrate multiple scales: genes for disease resistance, trees producing cones, stands with varying infection and mortality rates and suitability for restoration, landscapes for connectivity, and seed zones for adaptation. A wealth of data is needed for successful recovery in this complex system. A strategic approach, rather than an opportunistic one, is the only way to ensure functioning ecosystems are restored and sustained for the long term.



FIGURE 3. CLARK'S NUTCRACKER, OBLIGATE SEED DISPERSER OF WHITEBARK PINE AND PRIMARY SEED DISPERSER OF LIMBER PINE.

Knowledge and technology gaps addressed by this project

Because of their remote mountain habitats and slow growth, working with these species is extremely costly, requiring partners to focus their limited resources where they can be most effective. A prioritized, spatially explicit restoration plan is the “holy grail” of recovery, as it would greatly facilitate planning efforts while maximizing beneficial outcomes, and address both site-specific and landscape-level factors such as connectivity and health status. A spatial plan integrating targets at multiple scales is the most effective approach for species-level recovery as local activities tend to focus on sites with the most convenient access or sites that partners are most familiar with.

Knowledge and technology description

This project successfully achieved all three original project objectives through spatial data compilation and modelling using a number of open-source tools such as Google Earth Engine, R, Random Forests, ClimateNA, data management of complex and layered datasets on cloud servers and code on GitHub, analysis in ESRI Arc products, evaluation, validation and interpretation by subject matter experts, followed by reporting and extension.

- 1) Pilot spatial restoration models were successfully expanded to novel ecosystems further north and west of the areas they were initially developed for.
- 2) Predictive accuracy of key model layers was validated using ground and aerial survey data over a greatly expanded breadth and diversity of ecosystems. Systematic inconsistencies were addressed by adjusting data parameters before finalizing the model.

3) The model was implemented successfully to create a detailed province-wide spatial restoration plan for endangered pines across their Alberta ranges. Partners are also implementing the model in their respective jurisdictions to develop their own plans, for example in each Rocky Mountain national park.

Project performance metrics

Reflecting partner organization focus on conservation and land management rather than commercial enterprises, metrics were concentrated on Clean Resource Metrics, with one Program Specific Metric and two Project Success Metrics. Clean Resource metrics aimed to:

- Inform 1 practice by updating the draft restoration planning protocol for the Crown of the Continent Ecosystem and expanding it to the entire Alberta ranges of both species
- Establish 6 field demonstrations including 2 in novel environments
- Collaborate with 10 partners
- Train 7 highly qualified personnel
- Create 7 new jobs
- Publish 1 technical report

The Program Specific metric was a 65% reduction in landscape disturbance intensity, measured by survival of planted seedlings. Project Success metrics were to restore 30 hectares and host 2 knowledge sharing events.

Methodology

Crown of the Continent Ecosystem restoration spatial tool kit pilot model and final plan

The outline of our approach methodology is described in *Restoring a forest keystone species: A plan for the restoration of whitebark pine (Pinus albicaulis Engelm.) in the Crown of the Continent ecosystem*. (Jenkins et al. 2022) <https://doi.org/10.1016/j.foreco.2022.120282> (Fig. 4). They describe a pilot project completed in 2019 by a geospatial firm based on data contributed by partners to support restoration planning for whitebark pine in three areas. The pilot approach was successfully expanded (2020-2022) to include limber pine and the entire Crown of the Continent Ecosystem (CCE) encompassing northwest Montana, southeast BC and southwest Alberta. Modelling for the expanded area was done in ESRI ArcPro by geomatics experts from the USDA Forest Service and the Flathead Lake Biological Station. Using a tool kit comprised of the final spatial layers, and a revised logic model to prioritize activities, a preliminary spatial restoration plan was developed for the Alberta portion of the CCE. Treatments were implemented and monitored to gauge whether the layers accurately predicted high-value habitats and areas with the highest suitability for treatments such as planting.

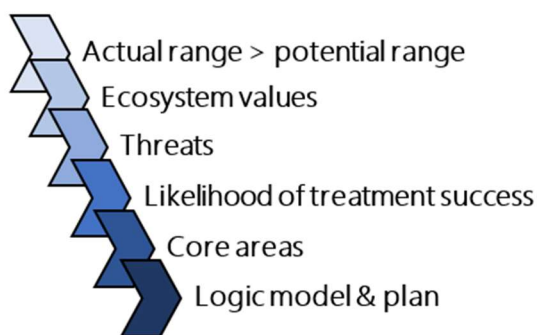


FIGURE 4. STEPS TO DEVELOP SPATIAL RESTORATION IMPLEMENTATION TOOL KIT AND PLAN.

Monitoring project effectiveness consisted of confirming in the field if layers such as potential range (habitat suitability and presence) and cone production (mature trees) were accurate, and determining how well likelihood of treatment success layers were predicting outcomes by surveying plots of planted seedlings.

Expanded and revised restoration spatial tool kit and plan for Canadian Rockies & Foothills

Project scope

The current project adapted and expanded the CCE proven approach to include all of the whitebark and limber pine habitat in Alberta as well as areas within partner jurisdictions east of the Rocky Mountain Trench (in both Alberta and BC) and all seven Rocky Mountain National Parks (Fig. 5). This encompassed a far greater diversity of habitats than the CCE, and a mix of jurisdictional data sources and land management priorities.

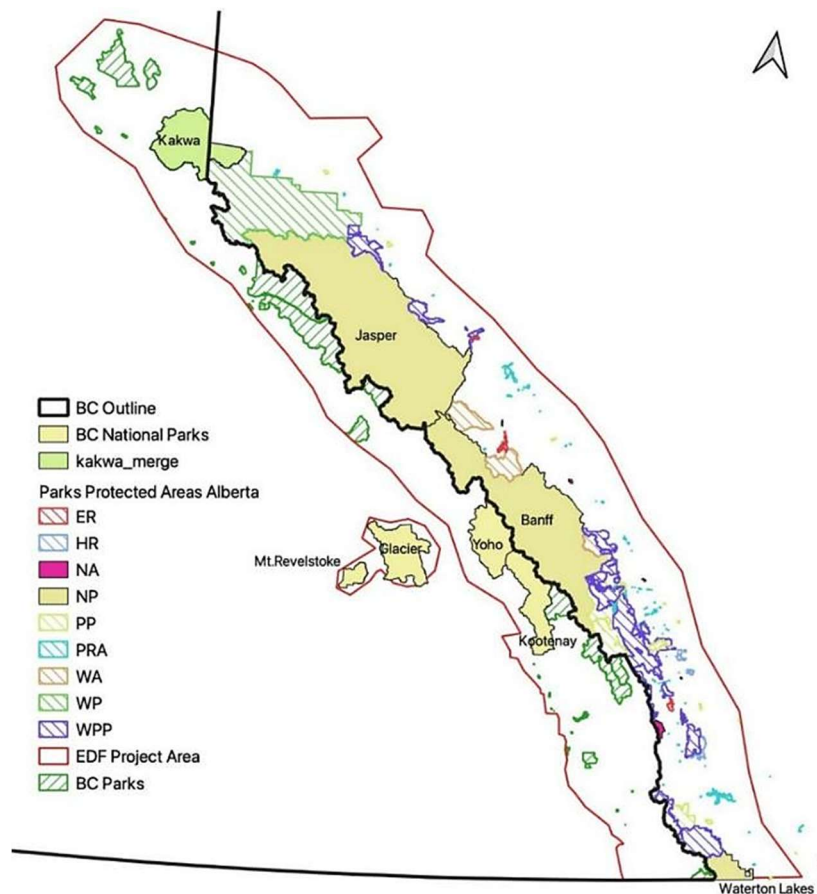


FIGURE 5. EXPANDED PROJECT AREA FOR SPATIAL RESTORATION PLAN MODEL DEVELOPMENT, COVERING THE FULL ALBERTA RANGES OF BOTH WHITEBARK AND LIMBER PINE.

Project team and data

A project team was assembled with team leads from each jurisdiction and the geomatics consultants, and managed by WPEFC, with biweekly meetings and periodic reviews of key model layers. Partners were asked to contribute data including presence and absence, health, ecosystem value attributes, threats, and recovery program data such as resistant trees and restoration sites. Other relevant layers including fire polygons and attributes, forest cover data, topography, climatic variables, and access were included at key steps. Provincial Conservation Data Centre records were included. Public data such as iNaturalist and eFlora records were checked for accuracy and those deemed acceptable by the project team were included.

Modelling process

Potential range layers form the foundation of the restoration plan. Analogous to suitable habitat under current and future conditions, potential range defines the possible area for any restoration activities, whether or not present conditions exist for the species to occur there. For example, a site that has suitable ecological attributes for whitebark and/or limber pine but is now fully occupied by other species due to decades of fire suppression is suitable habitat, as is a site that formerly had a stand of whitebark pine but none presently remain after a severe fire. All subsequent layers are clipped to this layer, so delineating potential range as accurately as possible is paramount. To create the potential range layers, team members were asked to compare options for species distribution model approaches based on outputs and statistics. Retained models with the highest agreement were generated by Random Forests, with a likelihood frequency cutoff of 0.5 indicating likely suitable habitat for the species (Figs. 6,7).

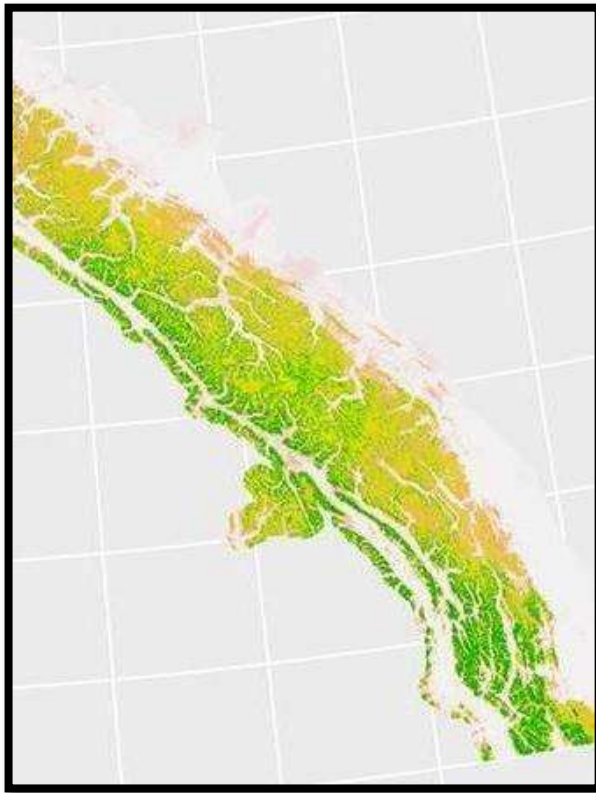


FIGURE 6. POTENTIAL RANGE OF WHITEBARK PINE IN THE PROJECT AREA: GREEN IS 1.0 PROBABILITY AND RED IS 0.5 PROBABILITY, WHITE IS >0.5 PROBABILITY.

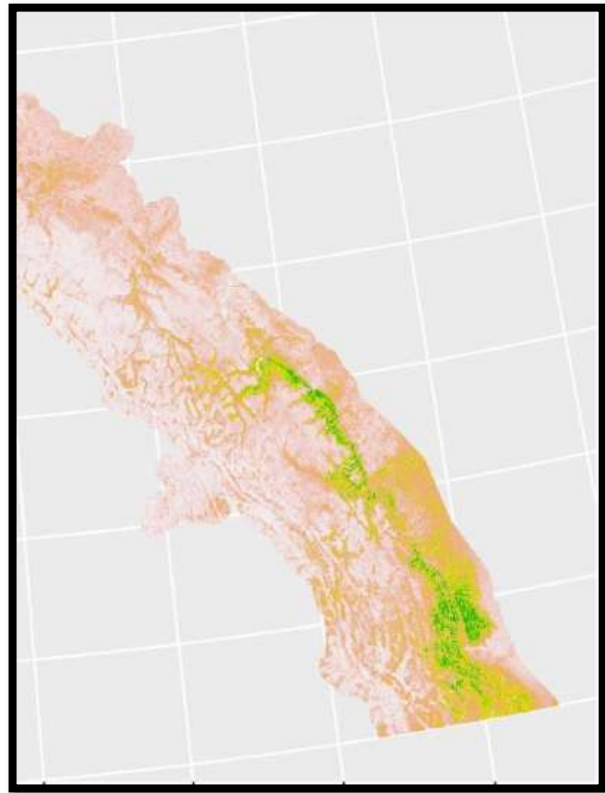


FIGURE 7. POTENTIAL RANGE OF LIMBER PINE IN THE PROJECT AREA: GREEN IS 1.0 PROBABILITY AND RED IS 0.5 PROBABILITY, WHITE IS >0.5 PROBABILITY. THIS MODEL OVERPREDICTS LIMBER PINE AND WAS LATER ADJUSTED.

Subsequent steps compiled topic-specific layers and partners compared parameter combinations and weights for biophysical attributes, threats, conservation values, and likelihood of success of different restoration treatments for each species. Each pixel (30 m resolution) was assigned a value for each layer or assemblage of positive or negative values and weights to result in a score for each step the model. Areas with high conservation value were classified into four categories based on the spread of values, where the two categories with the highest conservation values totalled 20-30% of the potential range as a target that is meaningful to achieve significant conservation objectives and also operationally feasible (Jenkins et al. 2022). These highest value habitats or

“core polygons” were aggregated into minimum 2-hectare areas to avoid slivers. Core polygons form the primary areas where restoration activities will occur.

Separate layers were generated for each restoration treatment that partners were likely to apply, such as planting seeds, seedlings, manual daylighting, brushing with equipment, cone collection, applying verbenone, prescribed burns, and several others. These layers reflected the “likelihood of treatment success” or LOTS, based on environmental conditions that would yield positive, neutral or negative outcomes, generating a pixel surface for each treatment showing areas likely to have varying levels of success for each species. Accessibility distance and slope were included in treatment feasibility layers for each jurisdiction reflecting different operability and travel constraints between partner organizations.

Desktop and field validation

Draft versions of the layers and a simple data collection layer were shared with partners at the beginning of field season 2024 to link feedback with spatial records. In regions north of the CCE with less empirical data due to their remote locations, extensive helicopter and road access validation data were collected on species, presence/absence, habitat suitability (yes/no), abundance, health and other species (Figs. 8,9). These data were all used to adjust the layers and improve the final model layers.



FIGURE 8. COLLECTING FIELD VALIDATION DATA BY HELICOPTER IN REMOTE SITES.

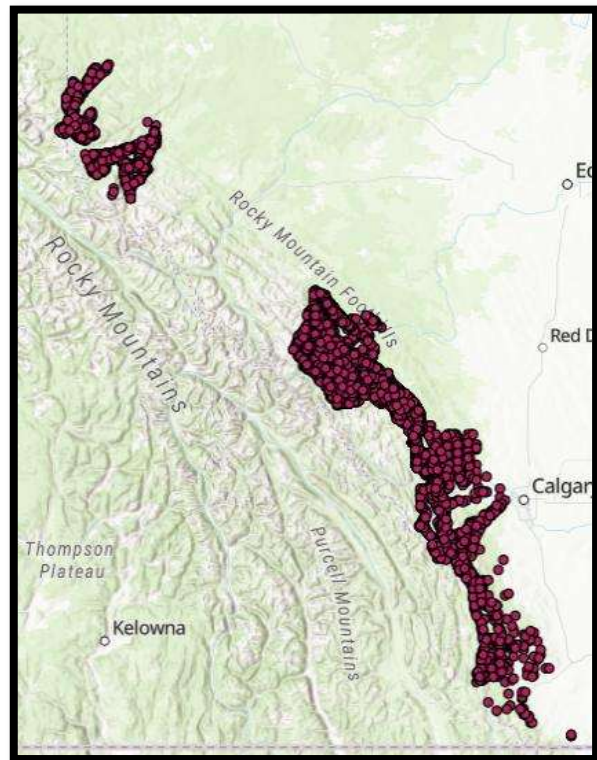


FIGURE 9. ALBERTA VALIDATION DATA COLLECTED IN 2024. MANY RECORDS CONFIRM ABSENCE. THE LARGE GAP HAS NO ENDANGERED PINES EAST OF THE NATIONAL PARKS

Restoration tool kit

The layers, as well as a 12x12 km grid to map landscape units that support connectivity through bird-and wind-mediated gene flow through seeds and pollen, were then combined into a downloadable layer package (toolkit) for each jurisdiction, as well as for the overall project area. This latter enables partners working across jurisdictions to identify sites with the greatest net benefit from treatments where there are opportunities to share resources, rather than focusing all efforts within their own respective areas, as some entire regions may have higher and some lower

overall priorities for species restoration activities. A guidance document with links to and descriptions of the key layers in the tool kit, ancillary layers that may be helpful when developing a plan (e.g., imagery, roads, topography, trails), and a step-by-step instruction list was developed and shared with partners to complete the package of layers that will be used to develop jurisdiction-specific restoration plans.

Spatial restoration plans

Each partner must develop their own logic model to prioritize treatments based on agency priorities, capacity and mandate. The Alberta plan logic model reflected the widely varying conditions across the large landscape included in the plan. A systematic approach assessed each 12x12 km grid square and documented whether it contained potential habitat for each species or not, and whether a component population existed (and if so, a minimum or target population). The logic model was applied to sustain or restore connected component populations in adjacent grid squares throughout the species' potential ranges. Core polygons were assigned treatments and priorities by reviewing the likelihood of treatment success layers in each polygon, as well as access, imagery, topography and other land uses to confirm compatibility and feasibility for treatment. Treatment Focus Area (TFA) polygons were then delineated for every treatment, identifying the treatment type, priority, amount, and area.

The TFA layer is the spatial component of the plan, accompanied by a comprehensive report outlining the plan goal, objectives, approach, methodology and restoration summary with examples, and a section on implementation guidance. This plan, completed in spring 2025, serves as a restoration recipe to recover these species in Alberta.

Outreach and extension

In spring 2025 and 2026, workshops were held to provide examples of prior restoration plans developed by applying the CCE tool kit, and illustrations of how to apply the current project tool kit to develop a restoration plan. To further raise awareness of the data, restoration tool kit and implementation plan, presentations to other potential end users and a webinar with nearly 150 internal government agency staff attending were delivered in 2025. An article describing the tool kit and plan was published in the Alberta Forest ministry forest health and adaptation newsletter with broad circulation. The plan is also described in a peer-reviewed journal article currently accepted and in review.

Project Results

Milestone 1 Complete CCE 5NP model validation and 5-year Spatial AB 5NP Restoration Plan

Completed. A process to integrate key data sources leading to a regional prioritized spatially explicit recovery plan was piloted by the Crown Managers Partnership in 2022. This project aimed to finalize and test the field validity of the plan developed by USDA Forest Service and Flathead Lake Biological Station geomatics experts using that initial spatial tool kit for the Crown of the Continent Ecosystem (CCE) which was **completed in field season 2023**. The primary model layer adjustment for Alberta was more detailed delineation of grassland vs. sparsely forested sites with suitable limber pine habitat, and similar delineation of areas that were not suitable potential range because of land use.

Interestingly, one Alberta site planted before the model was developed failed where the model indicated low likelihood of planting success. A partner organization in Montana reported confirming limber pine presence in a previously unsurveyed area based on model predictions.

Partners reported results generally aligned with model outputs, indicating the model is robust for the region.

The second part was to apply the adjusted tool kit to develop an operational restoration implementation plan for the region, which was **completed in March 2024**. The plan and spatial tool kit were submitted to the Alberta Government, as well as project funding partners. The plan encompasses all feasible restoration activities and sites for the entire region and prioritizes restoration activities.

Adjusted. Since WPEFC is currently the only organization currently implementing restoration treatments in Alberta outside of national parks (where Parks Canada leads), and funding for specific activities and areas varies annually based on grant opportunities, we did not pursue a 5-year plan with lacking funding for implementation, but choose implementation projects from the regional plan based on available funding.

Milestone 2 Draft Rockies and Foothills Spatial 5NP Restoration Plan

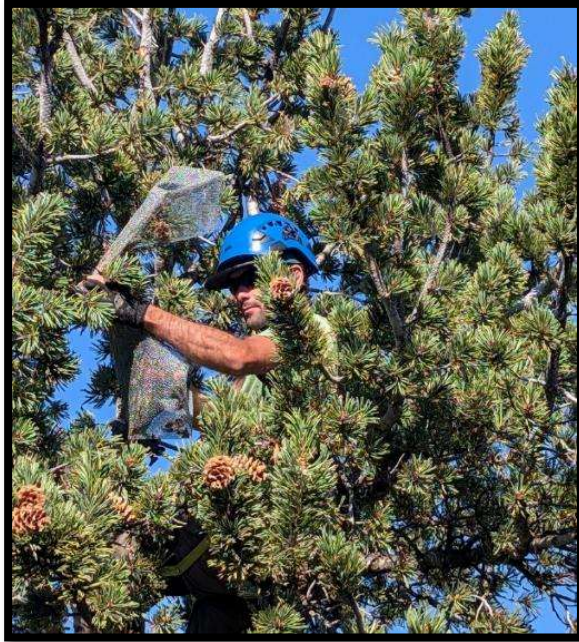
Completed. WPEFC successfully collaborated with partners to expand and refine the above approach to encompass the entire range of both species in Alberta, extending to all habitats east of the Rocky Mountain Trench, as key partners included all seven Rocky Mountain National Parks and Environment and Climate Change Canada, as well as the BC Government. This project was developed based on data submitted and reviewed by partners in each jurisdiction and compiled and modelled by a team of geomatics consultants with relevant expertise. Draft layers, which are the foundation of restoration plans, were submitted to partners in **spring 2024**.

Milestone 3 Validate and complete Rockies and Foothills Spatial 5NP Spatial Restoration Implementation Plan

Completed. Draft layers were reviewed in the office and also validated in the field in summer 2024 by WPEFC and partners. Validation feedback and data were used to refine the layers into a final spatial tool kit. Both jurisdiction-specific and project-wide versions were developed to support prioritization of restoration activities between partners should resource sharing opportunities arise. A detailed implementation guide was developed in fall 2024 and promoted through workshops and presentations to partners and potential end users.

Completed. The steps involved are described above under Methods in “Spatial restoration plans.” Based on this final Alberta tool kit (layer package), the spatial layer delineating Treatment Focus Areas and accompanying comprehensive plan comprises a detailed spatial restoration plan spanning the ranges of both species across Alberta with implementation guidance, covering about 4.3 million hectares. This plan was **submitted in March 2025** to several Alberta government departments whose mandates overlap endangered pine recovery, and presented to government staff and Canadian partners. This plan identifies and prioritizes every potential restoration treatment and site for Alberta, when coupled with the CCE plan for the southwest region, covering around 1 million hectares. This plan has proven incredibly useful to streamline annual planning and permitting work for Alberta endangered pine restoration.

Milestone 4 Implement & Monitor Restoration Treatments



Completed. To test proof of concept, priority restoration treatments for both the CCE plan, as well as the expanded Alberta plan, were implemented in 2023 and 2024 (Fig. 10). Sites selected included both typical and atypical sites selected by the models to evaluate the potential of the model for climate change impact mitigation (current and future growing season drought were both included as key stressors in the model). Monitoring in subsequent years will reveal the longer-term success of these various approaches. Year 1 results (2024 and 2025 data) are presented here and detailed below.

FIGURE 10. TO PREVENT WILDLIFE PREDATION, CONES FROM DISEASE-RESISTANT TREES MUST BE PROTECTED WITH WIRE MESH CAGES EARLY IN THE SEASON, AND REMOVED WHEN CONES ARE COLLECTED IN FALL WHEN THE SEEDS ARE RIPE.

Monitoring performance is important to inform adaptive management, especially as the climate changes in these sensitive montane and subalpine ecosystems. Strategies that may have worked in the past may need to be refined based on observed results and trends. WPEFC has shared the plan and results, the spatial data and progress to date with multiple partners, and will continue to do so. In the future we hope to establish a data hub to facilitate public and partner data access to areas of interest related to the tool kit as well as the underlying layers and associated data and reports and best practices. We envision this will ultimately become a living document, with periodic updates to the spatial layers and plan as wildfires occur, forest cover changes, and restoration proceeds.

Clean Resources Metrics

1. **Practices informed/influenced – met (1) and exceeded (2).** 2 updated protocols following validation were developed: 1 for the Crown of the Continent Ecosystem, and 1 for the rest of Alberta.
2. **Field pilots/demonstrations – met (6 sites: 2 in novel environments) and exceeded (11 sites: 2 in novel environments).** See Tables 1, 2 and Figure 11. These installations were supported in part by this project and in part by matching projects. Novel environments are atypical planting aspects and conditions for these species and are in bold font in the table. Maps and descriptions of each site follow. Where feasible, sites had both an area for operational bulk (mixed genotype) planting, as well as a monitoring section where long-term transects containing trees tracked by individual parent tree genetics were established and will be monitored over time for survival and health. Where there are no long-term plots, monitoring is done assessed using standard forestry silviculture plots, assessing performance using a 5.64 m plot cord with multiple plots spaced throughout the site.

The 2023 and 2024 summary presented here include only restoration numbers that align with the model layers and restoration plan, so planted grafts in seed orchards and planted seedlings in BC field sites are excluded from the restoration totals summarized here, although they are described in the annual restoration reports.

Although not included in the restoration totals for this project as the field work was supported by other projects, an additional 15,097 seedlings were planted in 2025 based on sites selected using the restoration modelling tool kit, restoring a further 32.0 hectares. Another 152 limber pine grafts from confirmed resistant elite trees were planted in the seed orchard in Waterton Lakes National Park. Table 2 summarizes the planting numbers and the following subsections describe each site. Table 3 summarizes survival monitored in 2025 of prior plantings both before and after the tool kit was available.

TABLE 1. RESTORATION SEEDLING PLANTING SITE SUMMARY FOR THE PROJECT WITHIN ALBERTA, BY YEAR. SITES IN *ITALIC* FONT ARE INNOVATIVE/ATYPICAL SITES SELECTED FROM MODEL PREDICTIONS IN CORE POLYGONS WITH HIGH LIKELIHOOD OF PLANTING SUCCESS. EXCLUDES GRAFTS AND SITES OUTSIDE ALBERTA. SURVIVAL INCLUDES ONLY CONFIRMED LIVING TREES AND NOT MISSING TREES IN PLOTS.

Site	Species	Bulk Trees Planted	Monitoring Trees Planted	Total Area Planted (ha)	Total Trees Planted	Land status	Year planted	Year 1 survival
Bob Creek (and MM)	LP	7,435	1,401	19.5	8,836	Wildland PP	2024	89%
Highwood	LP	2,424	0	4.9	2,424	PLUZ	2024	85%
Sheep River	LP	2,029	539	6.4	2,568	Prov Park	2024	19%
<i>Simpsons</i>	<i>LP</i>	<i>1,598</i>	<i>0</i>	<i>3.5</i>	<i>1,598</i>	<i>Private</i>	<i>2024</i>	<i>95%</i>
LP 2024 subtotal	LP	13,486	1940	34.3	15,426		2024	75%
Plateau East	WBP	810	401	2.4	1,211	PLUZ	2024	87%
<i>Plateau West Forest</i>	<i>WBP</i>	<i>460</i>	<i>346</i>	<i>2.2</i>	<i>806</i>	<i>Eco Reserve</i>	<i>2024</i>	<i>88%</i>
Plateau West Meadow	WBP	1,665	436	6.8	2,101	Eco Reserve	2024	17%
WBP 2024 subtotal	WBP	2,935	1183	11.4	4,118		2024	64%
Seedlings 2024 Total		16,421	3123	45.7	19,544		2024	71%
Prairie Bluff	LP	2,423	60	8.0	2,876	Wildland PP	2023	97%
Oldman North	LP	6,584	656	15.6	6,644	PLUZ	2023	91%
Waldron	LP	2,500	684	4.75	3,066	Private	2023	82%
LP 2023 subtotal	LP	11,507	1,400	28	12,586		2023	90%
Hailstone Butte	WBP	2,500	453	8.8	3,094	PLUZ	2023	97%
WBP 2023 subtotal	WBP	2,500	453	8.8	3,094		2023	97%
Seedlings 2023 Total		14,007	1,853	36.8	15,680		2023	92%
Combined total		30,428	4,976	82.5	35,224			78%

TABLE 2. RESTORATION SEEDLING PLANTING IN 2025 – SITES SELECTED BASED ON MODEL PREDICTIONS AND GROUND TRUTHING. EXCLUDES GRAFTS AND SITES OUTSIDE ALBERTA.

Site	Species	Bulk Trees Planted	Monitoring Trees Planted	Total Area Planted (ha)	Total Trees Planted	Land status	Year planted
Zoratti	LP	7,666	736	19.4	8,402	private	2025
NCC Christie Mines	LP	240	0	0.6	240	private	2025
Honeymoon	LP	2,300	724	5.3	3024	PLUZ	2025
LP 2025 subtotal	LP	10,206	1,460	25.3	11,666		2025
Sugarloaf	WBP	1,091	0	2.7	1,091	PLUZ	2025
Prairie Bluff WBP	WBP	1,720	620	3.8	2,340	Wildland PP	2025
WBP 2025 subtotal	WBP	2,811	620	6.5	3,431		2025
Seedlings 2024 Total		13,017	2,080	32.0	15,097		2025

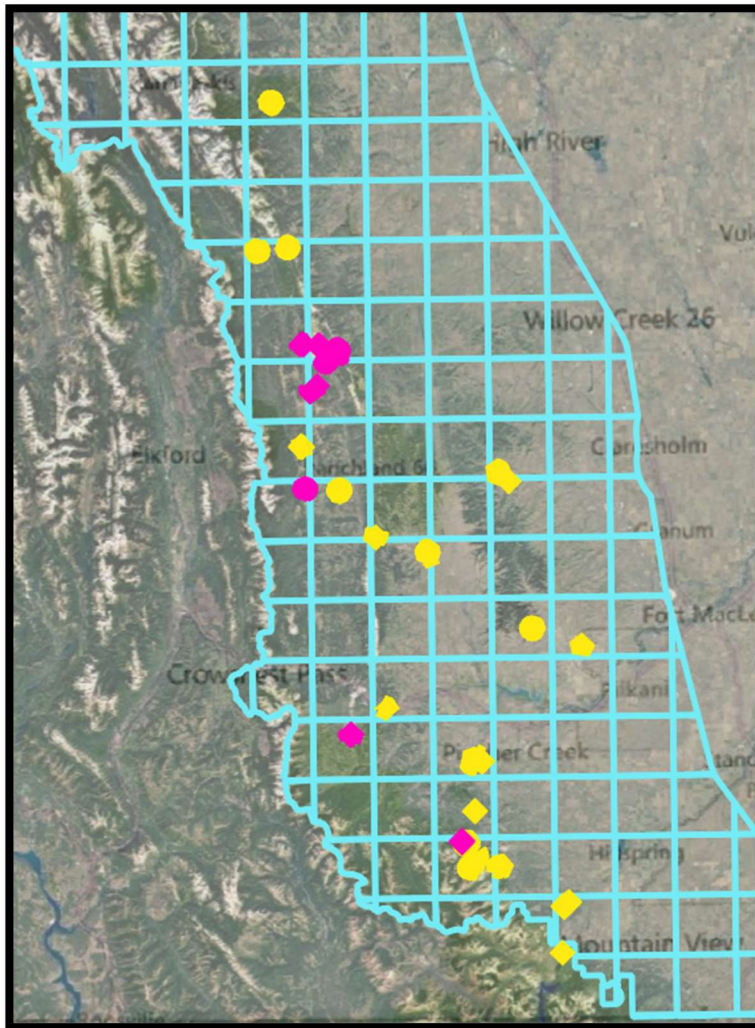


FIGURE 11. OVERVIEW OF 2023, 2024 AND 2025 PLANTED AND MONITORED SITES IN ALBERTA. YELLOW IS LIMBER PINE, PINK IS WHITEBARK PINE – POLYGON SIZES ARE BUFFERED TO IMPROVE VISIBILITY. BLUE IS 12X12 KM LANDSCAPE GRID SQUARES TO SUPPORT CONNECTIVITY PLANNING DEVELOPED FOR THE SPATIAL RESTORATION TOOL KIT

3. **Collaborators – met (10) and exceeded (16).** Collaborators developing the spatial tool kit included Parks Canada Agency teams from all 7 Rocky Mountain National Parks, BC Government staff from 2 ministries and several departments, a geomatics analysis team, and WPEFC team members, with additional support from ECCC as well as support from Alberta Innovates.
4. **Sector HQP Trained – met (7) and exceeded (10.5).** Geomatics specialists including staff and contractors both applied existing skills and developed new modelling and data management and analysis skills during the course of this project. Project managers (coordination and implementation leads) developed skills related to data management and QA, as well as project administration and documentation. Restoration specialists also learned novel approaches to seasonal restoration work in these atypical sites (relative to operational planting sites and methods), and to collect project-specific data.
5. **Actual new jobs created from project – met (7) and exceeded (8).** This project supported the creation of 2 geospatial analysis jobs, 1 project manager, and 5 restoration specialists.
6. **Publications – met (1) and exceeded (7 articles/reports + 5 presentations).** 1 detailed technical report to project partners detailing the geomatics processes used to develop the tool kit (and associated data on GitHub); 2 detailed spatial restoration plans and supporting guidance for Alberta submitted to GOA and project funders; 1 technical report to project partners detailing implementation guidance for the tool kit; 1 article describing the provincial restoration plan and data for GOA Forestry and Parks newsletter with circulation of ~350; 1 peer-reviewed article accepted and in review describing the restoration plan; 5 presentations to GOA staff and partners, students and potential users that include descriptions of the process, data and plan.

GHG Emissions Reduction Metrics

1. **% Reduction in landscape disturbance intensity – met (65) and exceeded (78).** This was interpreted as planting survival percent, which will translate into long-term carbon sequestration in restored habitats (Table 2). Monitoring results in 2025 for sites planted earlier are listed in Table 3 and Figs. 26-28 but represent sites planted before the implementation of this project so sites with year 3 and 5 monitoring data were not selected using the same approach.

Project Success Metrics

1. **Habitat restored, hectares – met (30) and exceeded (82.5).** See Table 1.
2. **knowledge sharing: extension events – met (2) and exceeded (5).** Presentations and webinars to partners and end users to raise awareness of the existence and opportunities to apply this plan and associated data. Another presentation is planned for October 2026 during the pending WPEFC Science and Management Conference.

Results summary

In Alberta limber pine was less abundant than potential habitat would suggest. Both whitebark and limber pine were absent from extensive areas in which potential habitat was mapped far to the east and north of their current ranges. Some fires were missing from government Wildfire layers (observed un-mapped burns were reported to GOA), and health was good in many remote areas north of the Bow Valley.

Higher priority was assigned to restoration sites in the core of the species' ranges in order to restore ecological function in currently occupied habitats to sustain the keystone functions of these trees.

Peripheral and never-occupied potential habitat is unlikely to ever be occupied by these species within the 100-year timeframe of this restoration plan because of the mechanistic factors affecting the demographics of bird-dispersed whitebark and limber pine, and also due to observed decadal declines in regeneration along the eastern limit of the species' ranges (Shepherd et al. 2025¹). A critical density of mature trees is needed to reliably attract the obligate seed disperser, Clark's nutcracker (McKinney et al. 2009²; Barringer et al. 2012³), and also to produce viable seeds (J. Krakowski, unpubl. data). When populations are too small, seed viability is very low due to selfing and all seeds produced are predated by wildlife, leaving none for natural regeneration. These types of sites were assessed in the logic model as the lowest priority.

This plan is being immediately applied in Alberta to deliver the maximum benefits for ecosystem recovery. While there was an enormous amount of up-front work during the first year of this project to compile and assemble the data driving the restoration plan, decision support using the finished plan is now impressively streamlined. WPEFC implemented restoration treatments in 2023 and 2024 in both typical, and predicted suitable but atypical habitats. In 2024 and 2025 WPEFC monitored survival 1-year post-treatment for sites planted in 2024 to give an early indication of their suitability under current conditions. Under this project and matching projects, over 80 hectares were restored by planting over 35,000 disease-resistant seedlings at 11 sites in priority restoration locations. Several hectares were thinned at one site to mitigate competition from subalpine fir, Engelmann spruce and lodgepole pine currently or potentially impeding whitebark pine development and reproduction.

With partner support and in addition to traditional restoration activities described here, a total of 233 grafts from the top 51 genetically resistant parents were established in existing seed orchards from 2023 to 2025. While not accessible yet due to snow, in June 2026 a total of about 300 grafts of the best of the best parental genotypes will be planted in the Elkhart whitebark pine seed orchard, including at least several dozen grafts from 8 Alberta parents; currently there are 8 Alberta parents of the 120 planted ramets and 18 genotypes there. These are not typical restoration sites where the model is applied so they are not counted in the seedling and area totals. Seed transfer provisions enable broad deployment of genetic material from these species, based on extensive studies of population genotypic frequencies as well as adaptive traits, so material from Alberta can grow well in the interior of BC, and material from the BC Interior can be transferred to Alberta.

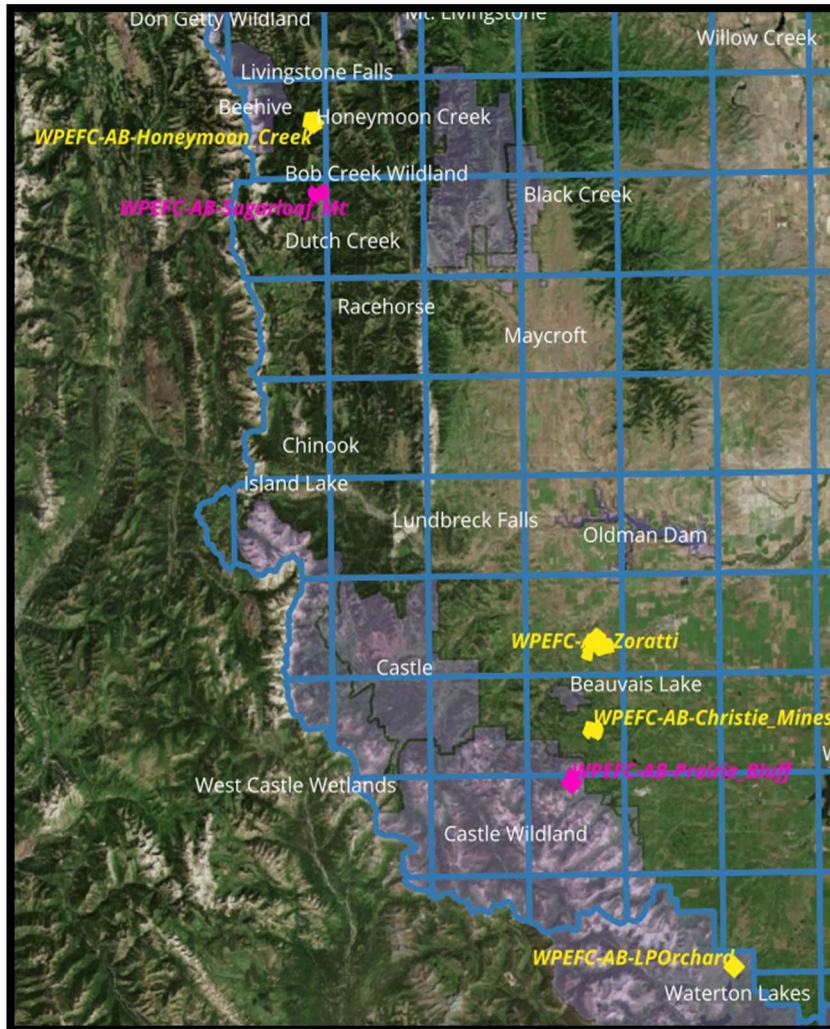
Overview – 2025 restoration activities

In addition to the restoration supported by this project, matching funds enabled WPEFC to plant 5 more sites in Alberta in 2025, restoring nearly 32 hectares with over 15,000 seedlings (Fig. 12). Activities focused on the southwest as the region with the highest restoration priority for the province and available matching funds for implementation. Sites were selected using the spatial tool kit habitat prioritization model supported by this project with high likelihood of treatment success for planting seedlings, and confirmed after ground truthing. We also monitored survival and vigour of sites planted the prior year (Fig. 13) to gauge survival in typical and atypical sites

¹Shepherd, B., Krakowski, J., Moody, R., Reid, I., Murray, M.P., Stafl, N., Sissons, R., Alger, G., Park, J., McLellan, C., Schwarz, C.J., 2025. Climate dominates geographic influences on whitebark pine and limber pine trends and landscape patterns in Canada. *Can. J. For. Res.* 55:1-19.

²McKinney, S.T., Fiedler, C.E., Tomback, D.F. 2009. Invasive pathogen threatens bird–pine mutualism: implications for sustaining a high-elevation ecosystem. *Ecol. Appl.* 19:597-607.

³Barringer L.E., Tomback D.F., Wunder M.B., McKinney S.T. 2012. Whitebark pine stand condition, tree abundance, and cone production as predictors of visitation by Clark's nutcracker. *PLoS One*, 7(5): e37663.



that were chosen with an eye to climate resilience on cooler aspects than typical for these species which are most prevalent on warm aspects.

Partner funding and considerable in-kind matching also supported planting 152 additional grafts in the limber pine seed orchard. Whitebark pine grafts were not ready for planting in 2025.

FIGURE 12. OVERVIEW OF 2025 PLANTED SITES. YELLOW IS LIMBER PINE, PINK IS WHITEBARK PINE – POLYGON SIZES ARE BUFFERED FOR VISIBILITY. GRID IS 12x12 KM LANDSCAPE GRID SQUARES DEVELOPED FOR THE SPATIAL RESTORATION TOOL KIT.



FIGURE 13. VIGOROUS, MULTI-STEMMED WHITEBARK PINE SEEDLING PLANTED IN A PROTECTIVE MICROSITE IN A MONITORING PLOT.

A brief overview of each 2025 planting site follows.

Sugarloaf Mountain – whitebark pine

The Sugarloaf Mountain whitebark pine planting site (Figs. 14-16) was a subalpine treeline site below a Wildfire lookout. Special permission was secured from Alberta Wildfire for the project, and special permission through a Temporary Field Authorization was secured from Lands to allow SXS access beyond legally designated trails to continue on the established but informal trail network to get planters and trees in. The Crowsnest Pass Quad Squad kindly volunteered to support our crew with transport logistics for an honorarium, pizza and presentation. The site was a rocky colluvial slope with variable aspects to choose from and abundant protective microsites. Whitebark pine was present but in poor health, and subalpine larch grew on the cool aspect. Well-drained mineral soils suitable for planting occupied pockets. All trees were planted in bulk with no long-term single-genotype monitoring plots established due to the challenging access – an 8-9 km hike each way gaining about 900 m, or repeated applications for the above access authorizations. This site will be monitored by silviculture style 5.64 m radius plots.

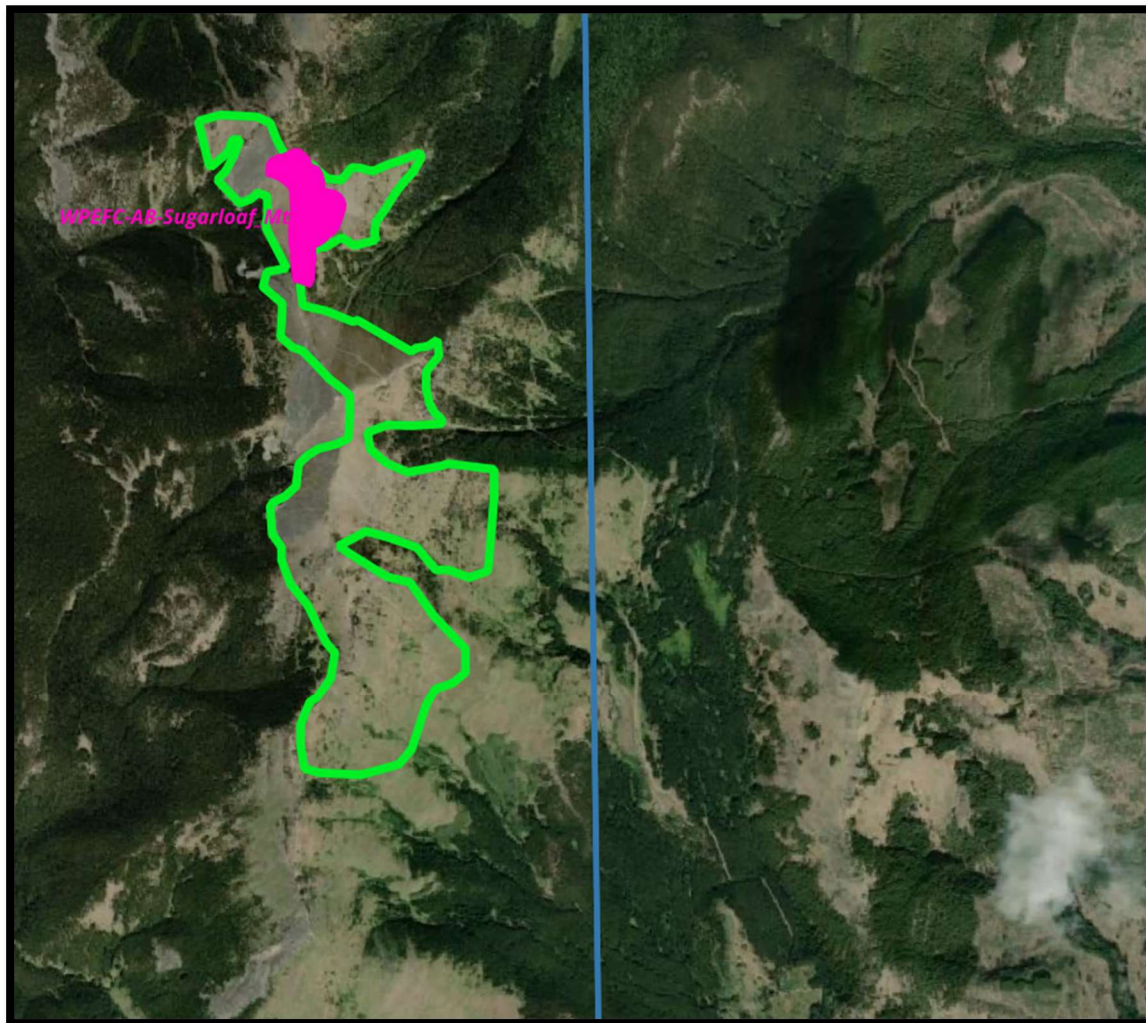


FIGURE 14. SUGARLOAF WHITEBARK PINE PLANTING SITE. PINK IS THE PLANTED AREA, GREEN OUTLINES THE POTENTIAL RESTORATION POLYGON, WHICH INCLUDES A WILDFIRE LOOKOUT TOWER. BLUE IS THE 12X12 KM GRID SQUARE BOUNDARY.



FIGURE 15. SEEDLING CACHE IN A WHITEBARK KRUMMHOLZ CLUMP



FIGURE 16. QUAD SQUAD VOLUNTEERS EACH PLANTED A SEEDLING

Prairie Bluff – whitebark pine

The Prairie Bluff whitebark pine planting site is within Castle Wildland Provincial Park, but accessed by a rugged steep network of gas well roads that were grandfathered into the park (Fig. 17). An OPAC research and collection permit, as well as a Temporary Field Authorization, and permission of a private landowner who owns several hundred metres of private property the otherwise public access road traverses were required. This site has good but weakly developed glacial till and is on a moderate southeast slope with stunted, windswept trees and krummholz as well as some hummocky grassy fescue-dominated areas with occasional shrubs (Figs. 18,19). Below the road a set of single-genotype monitoring plots were established and above the road was the bulk planting. Staff from non-profit partners Waterton Biosphere Region helped establish the monitoring plots.



FIGURE 17. PRAIRIE BLUFF WHITEBARK PINE PLANTING SITE (UPPER) AND MONITORING PLOT AREA (LOWER). PINK IS THE PLANTED AREA, GREEN OUTLINES THE POTENTIAL RESTORATION POLYGON.



FIGURE 18. CREW FIST BUMPS AFTER COMPLETING ANOTHER MONITORING PLOT IN 80 KM WINDS



FIGURE 19. KEEPING A STRAIGHT TRANSECT IS ESSENTIAL TO RELOCATE THE SEEDLINGS

Zoratti Ranch – limber pine

The Zoratti limber pine planting site is west of Pincher Creek on private land owned by a multigenerational ranching family devoted to environmental stewardship. They requested all 3 ridges be planted. Although the model output prioritized the western one, given the access, proximity for genetic dispersal, and ecological conditions, all three were planted (Figs. 20-22). Monitoring plots were set up at the bottom right to keep distinct from the bulk planting in the other areas. This site also has numerous genetically resistant trees and a long-term monitoring health plot so it is a very high-value area for the recovery program. With funding from separate projects, partner support from Waterton Biosphere Region and ALUS, as well as a matching contribution from the landowner, mobile electric fencing (Razer Grazer) was installed to protect the limber pine ridges and planted seedlings in the western two ridges from cattle trampling and breakage. This should also promote natural regen over time, and baseline data was collected to test its effectiveness. The planting site is in the montane zone, consisting of bedded tilted sandstone ridges with generally thin, rocky soils with localized patches of organic soils in spots with aspen and undisturbed fenced off grassland on the western sides of some ridges. We are very grateful for the support of the Zoratti family to allow us continued access to this beautiful and valuable site for limber pine in Alberta.

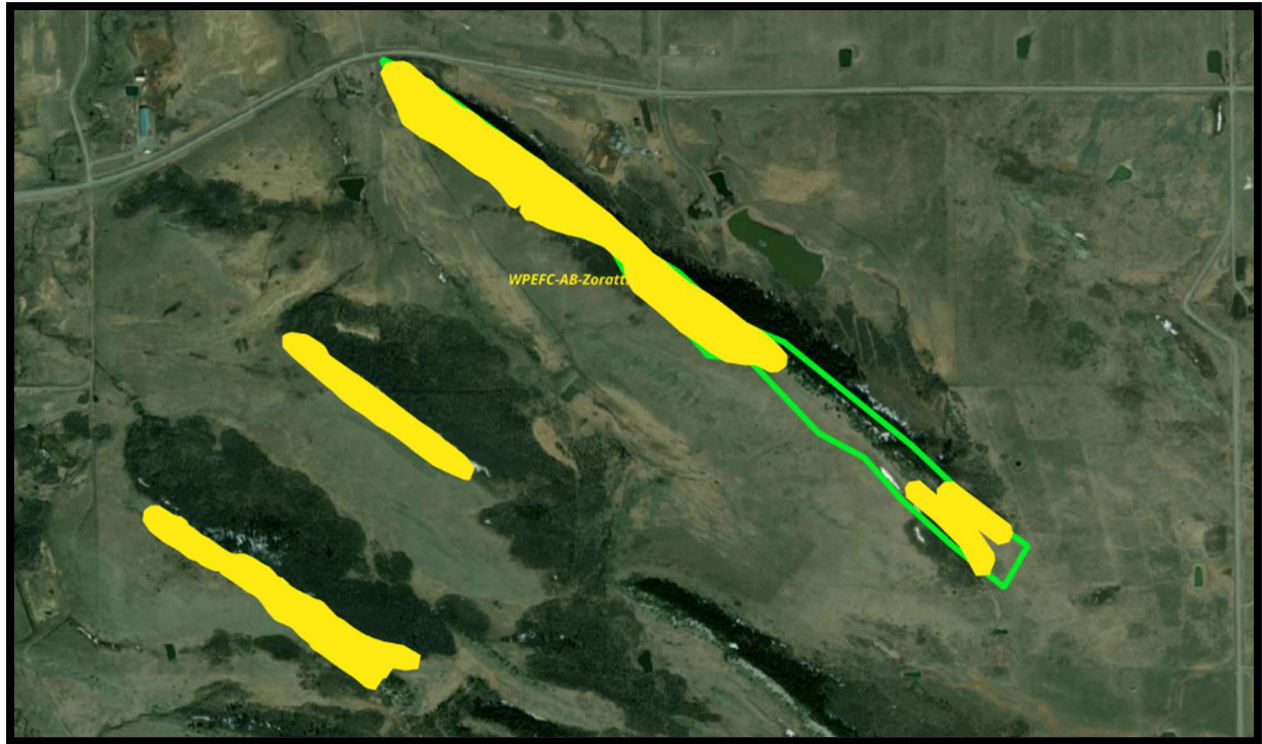


FIGURE 20. ZORATTI RANCH LIMBER PINE PLANTING SITE AND MONITORING (EASTERNMOST AREA), GREEN OUTLINES THE POTENTIAL RESTORATION POLYGON.



FIGURE 21. MATURE LIMBER PINE TREES AND NATIVE FESCUE ECOSYSTEM ON THE PROPERTY.



FIGURE 22. PLANTED SEEDLING IN A SHRUB MICROSITE.

Honeymoon Creek – limber pine

The Honeymoon limber pine planting site is on public land (PLUZ) above the Upper Oldman River close to the Honeymoon Creek Public Recreation Area in a montane forested moderately sloped ecosystem dominated by lodgepole pine and white spruce, with Douglas-fir and scattered aspen and cottonwood (Figs 23-25). The seedlings were planted in the opening on a warm-aspect slope. A Temporary Field Authorization was required for this site. Monitoring plots were flagged out and planted in a square in the middle and the rest of the site was bulk planted. The colluvial slope had rocky well-drained till.

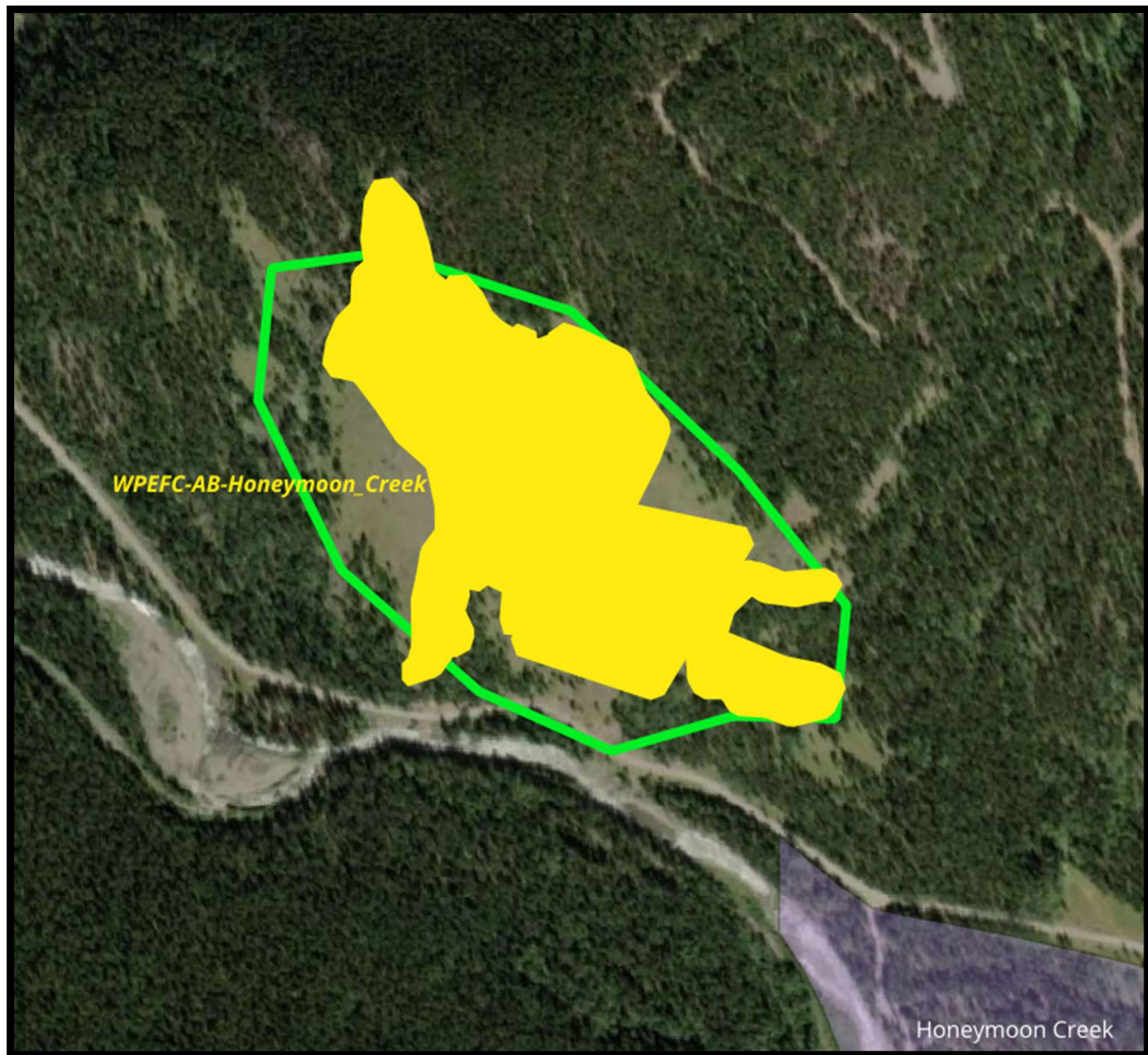


FIGURE 23. HONEYMOON CREEK LIMBER PINE PLANTING SITE AND MONITORING PLOTS (LOWER CENTRAL SQUARE SHAPE), GREEN OUTLINES THE POTENTIAL RESTORATION POLYGON.



FIGURE 24. HONEYMOON SITE AND UPPER OLDMAN RIVER.



FIGURE 25. PLANTING IN KINNICKINNICK ALONG A MONITORING PLOT.

NCC Christie Mines – limber pine

The NCC Christie Mines limber pine site is on private conservation land administered by the Nature Conservancy of Canada and owned by a conservation-oriented landowner southwest of Pincher Creek, both of whom granted access and permission. The site is a grassy south-facing ridge with sparse limber pine and an intact fescue ecosystem (Figs. 26-28). A small test planting was established to determine whether the site was suitable for seedlings or whether it may be too dry in summer drought conditions or possibly too competitive from herbaceous vegetation (even though there are mature limber pines, there were no seedlings or saplings). Should success after year 3 be good, we will plant more seedlings as there is ample room and supportive landowner.

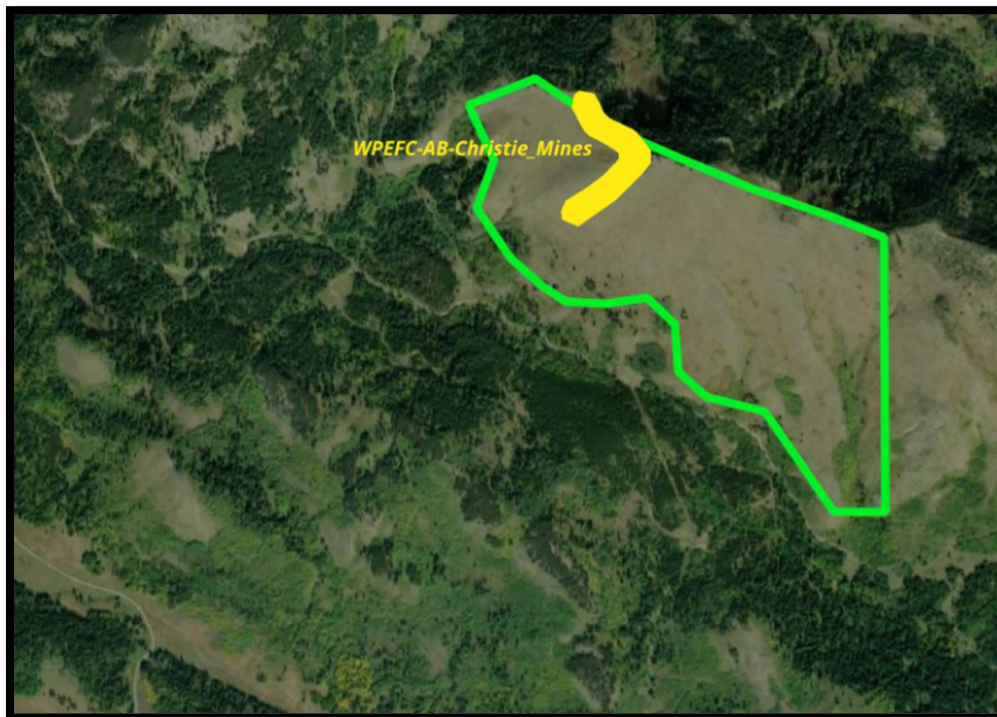


FIGURE 26. NCC CHRISTIE MINES LIMBER PINE PLANTING SITE.



FIGURE 27. PLANTING SITE WITH SPARSE LIMBER PINE AND PROTECTIVE LOGS AND SHRUBS.



FIGURE 28. ROCKY RIDGE WITH SPARSE LIMBER PINE.

Waterton Seed Orchard – limber pine

The limber pine seed orchard in Waterton Lakes National Park is the only one in the world. Parks Canada provided approval and supports this site through major infrastructure contributions, including an elk fence, irrigation system, rebar staking, and staff labour for planting, regular irrigation and maintenance (Figs. 29-31). A federal Environmental Impact Assessment was required for fencing. Volunteers also help plant grafts in the fall under the guidance of Parks Canada staff. This year the orchard was rogued (less resistant genotypes were removed) to free up space for more of the top tested genotypes. The rogued trees are still resistant, and were replanted in suitable habitat by Alberta Parks staff. The orchard should be full in 2026 or 2027, and

WPEFC is looking for another suitable site to supplement future seed supply as well as provide a backup if some emergency impacts this orchard.



FIGURE 23. LIMBER PINE SEED ORCHARD, WATERTON LAKES NATIONAL PARK.



FIGURE 24 PIIKANI NATION STUDENTS HELP ROGUE SELECTED GENOTYPES AT THE WATERTON SEED ORCHARD.



FIGURE 25. A VIGOROUS LIMBER PINE GRAFT IN THE ORCHARD, WITH STAKE AND ID TAG, IRRIGATION AND VEGETATION CONTROL.

Monitoring Prior Planting

Sites planted in 2020, 2022 and 2024 were monitored in 2025 (Table 3, Figs. 26-28). Seedlings are 2 years from seed when they are planted. A total of 170 monitoring plots, dozens of silviculture plots, and thousands of seedlings were assessed. These are environmentally harsh sites and early survival is very sensitive to weather, especially summer drought. Local site environmental factors have very strong effects on natural seedling germination as well as planted seedling success, even overriding larger-scale (long-term) climatic effects. While there is some expected attrition due to age, after 5 years one can be fairly confident that a planted seedling has a very good chance of persisting to maturity.

The site selection tool for the CCE was drafted in 2023 and refined in 2024. Prior sites were selected without the tool, and it is evident that survival was more variable, particularly for 2022 planted sites where survival declined steeply between years 1 and 3. Some sites selected in 2020 had excellent survival, while others had mediocre performance. Two sites selected using the model and planted in 2025 had poor year 1 survival, both with open exposed sites: Plateau West Meadow and Sheep River Prov Park. Even planting in microsites was inadequate at those two locations to protect against desiccation, which was the apparent cause of death for most trees. The performance target for survival was 65%. The 2022 planting fell below this, driving the overall average to 60%.

A prolonged extreme heat event (a “heat dome”) in June 2023 noticeably impacted survival of recently planted seedlings in exposed sites – some sites were surveyed in the weeks before, and revisited later in the season where there was a lot of new mortality. These weather anomalies are not reflected in climatic data that was used to build model layer, but can have severe effects on success. Similarly, a prolonged drought in late fall in 2019 led to planting failures across the region

(before this project). We need to make operational decisions based on average climate conditions, since nursery and planting work must be planned months in advance.

Blister rust was only observed in a few seedlings – their tiny surface area and short lifespans translate to a low likelihood of exposure at this point, and infection and mortality would be rapid so if killed by rust at this point, dead infected seedlings would not be detectable after a short time. It is possible some of the missing seedlings may have been infected, but the low observed frequency should reflect current seedling infection levels. Mature trees at these sites have far more infection as they have much more surface area and exposure duration.

TABLE 3. PRIOR PLANTING MONITORING SITES (ASSESSED 2025). LEFT IS %, RIGHT IS SEEDLING NUMBERS.

Years from planting / Site	Alive		Dead rust		Dead other		Missing		Total
Age 5 (planted 2020)	72.2%	127	0.0%	0	1.7%	3	26.1%	46	176
Savanna2	73.0%	46	0.0%	0	3.2%	2	23.8%	15	63
Savanna1	87.1%	27	0.0%	0	0.0%	0	12.9%	4	31
Plateau_Mt	46.2%	24	0.0%	0	1.9%	1	51.9%	27	52
Sentinel	100.0%	30	0.0%	0	0.0%	0	0.0%	0	30
Age 3 (planted 2022)	32.2%	270	0.0%	0	38.2%	320	29.6%	248	838
Burtons	35.6%	96	0.0%	0	17.8%	48	46.7%	126	270
Spades	30.6%	174	0.0%	0	47.9%	272	21.5%	122	568
Age 1 (planted 2024)	66.8%	2000	0.0%	1	30.3%	907	2.9%	88	2996
Bob_Creek	89.1%	1196	0.0%	0	7.8%	105	3.1%	41	1342
Highwood	85.0%	23	0.0%	0	15.0%	4		0	27
Plateau_E	86.7%	346	0.3%	1	11.3%	45	1.8%	7	399
Plateau_W_Forest	88.0%	293	0.0%	0	11.1%	37	0.9%	3	333
Plateau_W_Meadow	17.2%	75	0.0%	0	82.6%	361	0.2%	1	437
Simpsons	95.0%	38	0.0%	0	5.0%	2		0	40
Sheep_River_PP	18.6%	90	0.0%	0	74.0%	359	7.4%	36	485
Total	59.8%	2397	0.0%	1	30.7%	1230	9.5%	382	4010

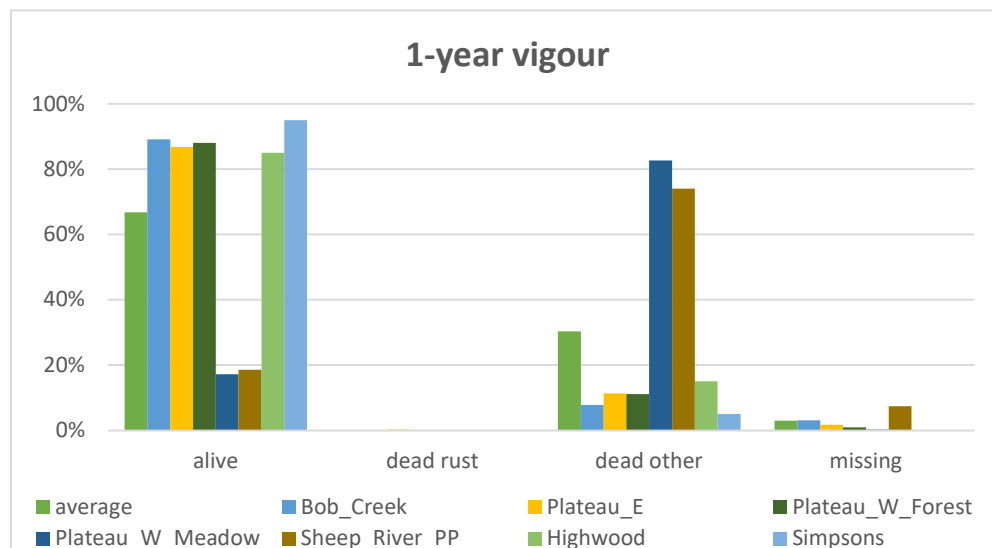


FIGURE 26. VIGOUR OF SEEDLINGS PLANTED IN 2024.

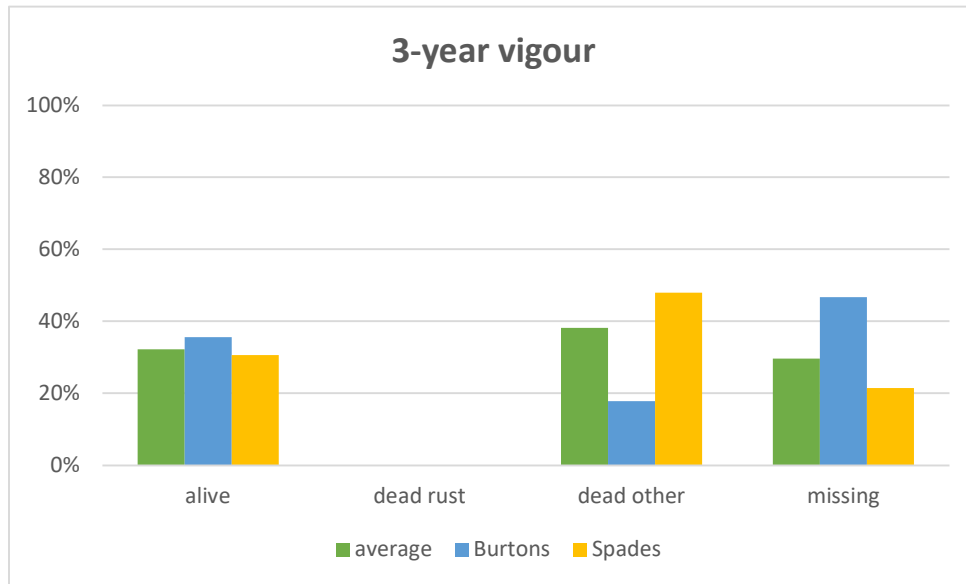


FIGURE 27. VIGOUR OF SEEDLINGS PLANTED IN 2022.

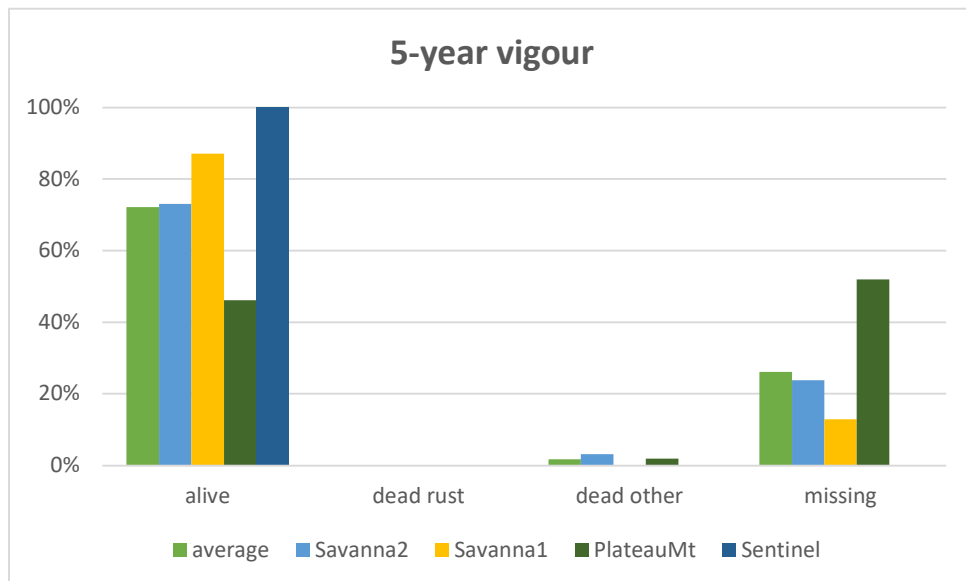


FIGURE 28. VIGOUR OF SEEDLINGS PLANTED IN 2020.

Key Learnings

Key learnings and importance

Key learnings from this process emphasize the importance of early and active engagement by partners in such a complex and data-heavy project. There were noticeable differences in model output resolution and predictive reliability for regions that had more complete data coverage from the various project layers as well as more validation and review input.

Including only Canadian data for this project resulted in lower model predictive accuracy for southern regions due to edge effects, particularly for limber pine whose northern limit in Canada includes about 15% of its range, with the majority of the species' distribution in the US Rockies and Great Basin. Including US data would have improved limber pine model outputs substantially. We have since acquired this data in anticipation of a future opportunity to refine those layers. And

the prior CCE models cover the southern part of the project area with good accuracy as they include abundant data from both US and Canadian partners, so they have been used for planning for those regions.

The complexity of the project and the technical nature of the restoration layer package (tool kit) necessitated detailed guidance to support partners in its application to develop their own restoration plans. In particular the definition of potential range is a subtle concept that does not reflect actual occupancy, but needs to be fully grasped by all partners as that layer underpins all others in the spatial modelling. Online or in-person workshops also were instrumental in walking partners through steps of the tool kit application within the context of each jurisdiction. Biological and ecological recovery goals form the foundation that integrates all recovery planning, within which jurisdiction-specific priorities and land management objectives and constraints are considered during plan development.

Monitoring results of restoration treatments continue to inform refinements to treatment implementation and planning. Sharing results among partners at forums like webinars, workshops and meetings helps identify emerging issues and novel ways to test assumptions or implement treatments. Pooling data provides important context, clarifying whether challenges are localized in space and/or time, or systemic across a region or range-wide.

Filling knowledge gaps with project results

This project has been instrumental in adapting and expanding a piloted approach to spatial restoration for these species. The resulting spatial restoration tool kit encompassing the entire species' ranges in Alberta is now operational. The layers have been used to develop a detailed operational restoration plan for the province, following a logic model adapted to the ecological and logistical conditions of each region that sets priorities for different activities and areas. The resulting plan, if implemented, will lead to the recovery of both limber and whitebark pine in Alberta. Fully implementing this plan will take many decades and millions of dollars, but it is possible to make good progress by focusing on the highest priorities first, and continuing as resources allow.

Broader interest and applicability

Conservation biologists working on other Alberta and national species at risk recovery programs in GOA, ECCC, Parks Canada and Canadian Wildlife Service have expressed great interest in this approach. It is scalable and applicable to any biological system, if enough supporting information is available to define, and spatial data is available to parameterize, variables influencing the species' potential range, threats, ecological values, and factors influencing treatment success. A strength of this approach is that while quantitative data is ideal, qualitative data in categorical or ranked formats can also work, provided data are scaled and/or weighted to align with quantitative layers.

Authorizations

All requisite permits were secured for these sites before planting could begin, including Alberta Parks OPAC research and collection permits, Ecologist and Lands Officer approval For Sheep and Goat Mitigation, Range Agrologist and other Lands referrals, written authorizations from grazing leaseholders, Temporary Field Authorizations for planting and helicopter access, private landowner access and planting permission, Alberta Forestry seedlot registration, Alberta Forestry genetics species-specific seed transfer and seedlot composition approval.

WPEFC has been working to engage GOA to identify options to streamline red tape by reducing the complexity and number of authorizations and the associated cost of their administration for this habitat restoration work in non-operable areas that do not have land use conflicts, soil disturbance or industrial installations, but the number of approvals required each year continues to increase.

Outcomes and Impacts

WPEFC promptly applied the tool kit and plans for their intended purpose, to guide restoration activities in priority habitats in Alberta. Sites were chosen distributed between the 12x12 km landscape units to support connectivity through seed and pollen dispersal, and reduce overplanting in a single unit. To test whether the product delivered future-proofing results as intended, both traditional and atypical restoration sites that had promising model outputs were selected for treatment. Once selected sites were identified, crews verified their suitability in the field, and delivered restoration treatments (typically planting seedlings to restore functioning populations). To further advance the proof-of-concept, sites were monitored 1 year post treatment for survival. Results are compiled here as well as to support provincial and national reporting, to evaluate trends and promote adaptive management.

Practices informed/protocol developed: The development of the restoration toolkit protocol (step by step guide and GitHub code) are outcomes that set out a template that can be adapted to other conservation challenges, or used to expand the scope of this project.

Publications: the final spatial restoration plans and accompanying layers are key outcomes that fulfill the overall goal of this project. See detailed list below.

Associated extension augments their potential effectiveness by raising awareness of the plans and data among partners and enabling broader implementation and data access by other organizations.

Field demonstrations and reduction in disturbance intensity are where the rubber hits the road, demonstrating the effectiveness of the planned ecological restoration treatments identified in the restoration plans in various environments, based on monitoring results.

Increased capacity and up-skilling through hiring and training professionals to advance their spatial data analysis skills, project management capacity, and environmental restoration portfolio broaden opportunities for comparable work not only for these individuals and their employers, but for participating partners and WPEFC.

Publications and presentations

Publications and reports

- Spatial Restoration Plan for Endangered Whitebark and Limber Pines in Alberta's Crown of the Continent Ecosystem – project report submitted to Alberta Innovates and other project funders and to GOA March 2024
- 5NP Canadian Rockies Whitebark and Limber Pine Restoration Toolkit – project documentation by geomatics contractors January 2025
- Endangered Pine Spatial Restoration Implementation Plan – Interim User Guide – implementation guide to project partners January 2025

- A Recipe for Success: Spatial Implementation Plan to Restore Limber and Whitebark Pine in their Alberta Ranges – project report submitted to Alberta Innovates and other project funders and to GOA March 2025
- One Plan to Rule Them All – article in GOA Forest Health & Adaptation newsletter April 2025 describing restoration plan
- One plan to rule them all: Applying the conservation standards to coordinate restoration of Canada's degraded endangered whitebark and limber pines across jurisdictions – *article in review (accepted, revisions submitted)* to Canadian Journal of Forest Research, describes data and restoration plan (can provide when approved by journal)

Presentations

- Conservation Standards Working Group (national recovery team) – workshop including AB & group implementation updates March 3 & 4 2026
- Recovering Alberta's endangered whitebark and limber pines – presentation to Lethbridge Polytechnic Ecological Restoration program November 19 2025
- Rockies 5NP Restoration Toolkit – presentation to Canadian 5-needle pine working group May 20, 2025
- Back from the brink: Recovering Alberta's Endangered Whitebark and Limber Pines – webinar to GOA staff May 12 2025
- Alberta's endangered pine program database – presentation to GOA staff April 11 2025 also describes the restoration plans and tool kit

Benefits

Economic

This project provides economic benefits by targeting limited resources to sites that yield the biggest bang for the restoration buck in terms of habitat with the highest value, and treatment with the highest likelihood of success. Once a plan is developed, it significantly expedites operational planning for restoration projects, and also facilitates tracking progress. This project created 8 jobs in a range of positions from data analysis to project management to ecological restoration and trained 8 HQSP in related applied skills. This project matched a project supported by the ECCC Environmental Damages Fund and was matched by funding from Parks Canada Agency in order to include their jurisdiction in the modelling project to support restoration planning in each of their national parks.

Environmental

The main objective of this project was to support data-driven environmental restoration. Altogether with matching support, over 80 hectares of degraded priority habitat in montane and subalpine ecosystems were restored through planting over 35,000 disease-resistant seedlings. Both typical and atypical sites were chosen to test model outcomes. Seedlings are especially vulnerable to (short term) weather conditions during the establishment phase, but long-term results will have to wait until 10 years post-establishment when seedlings are likely robust enough to persist for the long term in the absence of site disturbance. Survival in the atypical sites exceeded that of the typical sites following 1-year monitoring, however, supporting the selection of cooler aspect sites where available. The long history of fire suppression in Alberta severely limits the availability of such sites, however, as most cool-aspect sites are fully occupied by competing

species and are not available for planting slow-growing whitebark or limber pines until major disturbance opens up the canopy to promote their development.

Social

There is broad public support for ecological restoration projects in Alberta, and there is also a high level of support by industry, landowners, cattlemen and government for restoring whitebark and limber pine, as evidenced by the many approvals and referrals needed to receive authorizations for this work. A diversity of successful restoration sites that can serve as demonstrations to the public, government, and other groups is a powerful tool to show progress, help others understand the logistical challenges associated with restoring these species, and promote partnerships and support. This toolkit comprises a biophysical information source that can be used to complement Indigenous land management and restoration work involving these species by highlighting areas of good or poor feasibility for different treatments, and high ecological priority sites. Aligning restoration in Alberta with work occurring in national parks and BC also emphasizes these same messages of science-based successful restoration, and offers demonstration of resource sharing among project partners.

Building innovation capacity

This project has also resulted in the compilation and development of a significant resource: a repository of key spatial data for endangered pine recovery in the project area, including all of the Alberta ranges of both species. The data consists of raw and cleaned layers, derived model layers such as species' potential ranges and likelihood of treatment success, and supporting ancillary layers such as the landscape grid to support planning. The finalized restoration plans and accompanying spatial treatment layers also comprise new resources developed for this project that integrate these technologies and tools.

Staff and contractors working on this project have developed new geomatics and project management skills, and restoration practitioners have learned new approaches to establishing and monitoring field sites specific to these species. The potential for broader application and expansion of this approach to other areas is high, which has the potential to foster similar innovation capacity in more potential partners and technical staff.

Recommendations and Next Steps

Long term plan

The long-term plan for these data is to make them available to partners to advance recovery by targeting priority restoration activities to the best sites in Alberta and the project area. Consistent with our original proposal, we do not intend to commercialize or patent the data to minimize barriers to partners including other non-profit organizations and Indigenous communities who may want to participate in restoration.

Partner engagement

Continuing to engage potential partners in Alberta restoration is necessary to promote awareness and potential support for implementation. In particular Alberta government agencies should be familiar with the plans and the data and be prepared to proactively share it upon requests to help review project referrals that overlap the habitats of these species, and to support project opportunities. WPEFC will feature this project in upcoming presentations and articles to target audiences as opportunities arise.

Spatial land base dispositions pending for existing restoration program components are held by GOA, and there is a current 3-year backlog in their establishment, substantially increasing the risk that restoration sites, disease-resistant trees, and long-term installations will be impacted by development. WPEFC continues to follow up with GOA to check on the status of these restoration dispositions, and to submit new ones annually.

Follow up project: model refinement with additional data

Supporting cross-jurisdictional planning was key to improve data resolution and model reliability at jurisdictional boundaries – species and habitats don't suddenly stop at borders. Incorporating adjacent data minimizes edge effects and improves model accuracy and planning outcomes. As noted above, WPEFC now has data from the US ranges of these species to improve model accuracy for the southern parts of the species' ranges in Canada. Layers also may require periodic updating to reflect wildfires, restoration progress, and forest cover and access changes.

Follow up project: data hub

As awareness of these data and plans grow, the increase in data requests to WPEFC for spatial information and plans related to endangered pine recovery indicates the need for a data hub so partners can easily query and access relevant data and supporting information for their needs without requiring WPEFC to spend extensive time accessing, reviewing, compiling and interpreting data to respond to each request. Some data is associated with private property and some may require data sharing agreements so additional project development and support is needed before a data hub can be developed to meet partner data needs in a more streamlined way.

Knowledge Dissemination

A key aim of this project was to ensure government regulators and end users were aware of the data and tools developed for this project and how to use them. While the restoration plan was accompanied by a detailed report and implementation guidance, targeted presentations serve as an effective way to convey key messages relevant to each audience.



Once the tool kit layers were finalized, WPEFC held workshops with project partners structured to walk them through the steps of how to apply and interpret the tool kit layers in order to develop spatial restoration plans for their respective jurisdictions and align with higher level recovery goals for population distribution objectives. Each Rocky Mountain National Park management unit is developing their own restoration plans.

The plan for Alberta is complete and WPEFC has distributed this plan to many GOA staff and described the data and plan in a webinar attended by over 150 staff.

FIGURE 29. GOA FOREST HEALTH OFFICER IN THE FIELD HELPING WPEFC COLLECT WHITEBARK PINE CONES.

BC is working on a plan to warehouse and distribute their spatial layers via the BC spatial data warehouse to support partners who may want to apply them, as well as laid the groundwork for future plan expansion to other areas.

The Alberta restoration plan and shapefiles were submitted to numerous Alberta Government departments in the Environment and Forest ministries with explanatory emails to provide context. Recipients included about two dozen operational and management staff whose scopes of work overlap endangered pine recovery and restoration, and were also attached as part of permit reporting requirements. Extension activities to raise awareness of this plan and the associated data included delivering a webinar with nearly 150 Alberta Government staff, over a dozen online and in-person meetings with government and other potential end-users describing the available data, and presentations to groups of subject matter experts and endangered pine restoration supporters highlighting the plan and its applications. Further presentations are planned for upcoming conferences and workshops. An article was published in the Alberta Forestry and Parks “Bugs and Disease” newsletter with a circulation of about 350 internal and external recipients. Another presentation on this topic is planned for the upcoming WPEFC Science and Management Conference in October 2025.

Ensuring government staff have copies of and are aware of this plan and the supporting data can help effectively support recovery should the province decide to pursue its own restoration projects, or support other organizations, industry, and/or landowners to undertake restoration projects. Ensuring government departments are aware of locations of key program components including rarer disease-resistant trees, restoration sites, and long-term research plots should help protect them from development impacts. Where development is proposed or approved adjacent to or overlapping these species, regulators should include permits conditions related to these species promoting best practices, and measures aimed at preventing, minimizing, and – if need be – mitigating impacts by implementing restoration options outlined in the restoration plan.

WPEFC and aims to post the data and the restoration tool kit and plan on our website once information privacy considerations related to private land are fully addressed. WPEFC is actively seeking support to develop a data hub to facilitate automated data compilation and access for partner requests as the number of data requests continues to grow and pressure the limited capacity of WPEFC.

Conclusion

This project culminates years of collaboration to fill a long-identified priority gap to support endangered pine recovery in Canada. The structure is now in place, including a range of critical spatial data relevant to the species’ biology, ecology, threats, restoration site selection, and treatment success potential. Essential layers are combined into a package or tool kit designed to develop spatial restoration plans that will lead to recovery objectives and goals, subject to monitoring and adaptive management. There are explicit guidelines on how to apply the spatial tool kit across the landscape to prioritize treatments and maintain or rebuild connectivity between populations. And Alberta now has a comprehensive and spatially explicit restoration plan and guidance document to restore endangered pines throughout the province, that has been shared with and presented to numerous government agencies and partners. This plan can be implemented by anyone with the interest and capacity to support restoration in Alberta, and the approach can be refined and expanded, should a future opportunity arise.

Acknowledgements

This achievement would not have been possible without the support of Alberta Innovates and our other key project partners Environment and Climate Change Canada (Environmental Damages Fund) and Parks Canada Agency. Other partners and collaborators supporting data access, compilation, review/quality control, field work, and project management and refinement include:

- Natural Resources Canada
- Alberta Government: Forestry and Parks, Forest Areas & Wildfire: Calgary, Rocky Mountain House, Edson, Grande Prairie; Lands: Ecologists, Range Agrologists; Environment & Protected Areas: Species At Risk, AB Parks
- BC Government: Ministry of Water, Land and Resource Stewardship, Ministry of Forests, Ministry of Environment and Climate Change Strategy: BC Parks
- Waterton Biosphere Region & volunteers
- Nature Conservancy of Canada
- USDA Forest Service Region 6, Dorena Genetic Resource Center
- Crown Managers Partnership
- Piikani Nation, Stoney Nakoda Nation, Tsuut'ina Nation, Aseniwuche Winewak and Alberta Métis Nations
- West Fraser Cochrane
- Many private landowners
- Ahlstrom Air, Yellowhead Helicopters, HeliSource, Hy-Ridge Helicopters, LR Helicopters, Alpine Helicopters
- Our staff, contractors and volunteers