Genetic conservation strategy for whitebark pine in British Columbia

Genetic Conservation Technical Advisory Committee

Forest Genetics Council

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Executive Summary

Despite its well protected status, whitebark pine (*Pinus albicaulis*) populations are suffering very rapid mortality and more proactive management approaches are needed to mitigate its decline, especially over the short and medium terms. To ensure they are effective, a unified framework is needed to implement objectives identified for whitebark pine conservation across the province. A genetic conservation strategy for whitebark pine across British Columbia will provide key guidance to support the various initiatives being undertaken by disparate agencies to conserve whitebark pine communities. Current, accurate baseline inventories of whitebark pine ecosystems that incorporate forest health and disturbance will be the foundation to guide management activities and priorities at the landscape level, and – where information exists – at the stand level, as that is where we can best apply sampling criteria for genetic conservation.

Genetic conservation must incorporate differentiation among populations and families to ensure the range of genetic diversity is sustained across the landscape. This can be achieved by: 1) monitoring its status in protected areas, 2) identifying individuals putatively resistant to (or tolerant of) blister rust and mountain pine beetle and collecting their seed; 3) testing for heritable resistance; and 4) *ex situ* conservation, including seed storage. Restoring whitebark pine across the landscape can be achieved through a combination of ecosystem management, seed collection, and seedling production. Establishing seed production areas comprised of tested resistant material as an *inter situ* measure is a low-priority option at this time but would provide a low-cost, long-term option for accessible seed. Inter-agency collaboration and extension involving many partners is needed to ensure resources and outcomes are optimized, building on the expertise and strengths of participants.

Potential identified partners include community groups, recreational users of whitebark pine habitat, First Nations whose traditional territory contains whitebark pine populations, licensees whose operating areas include whitebark pine stands, provincial and federal government agencies, academic institutions, local and regional governments, naturalist clubs, and consultants with expertise in mapping, cone collection, and ecological restoration. Cone collection from putatively resistant trees is the top priority for this species in the short term. Follow-up key activities over the short- to medium-term include optimizing procedures for seed processing, germination and storage; screening and testing by family for blister rust resistance; identifying trees with hypersensitive responses to bark beetle attacks; and producing a supply of rust-resistant seed for *in situ* restoration.

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Table of Contents

List of Acronyms

BEC	Biogeoclimatic ecosystem classification
CDC	Conservation Data Centre (branch of MOE)
CFS	Canadian Forest Service (federal)
COSEWIC	Committee On the Status of Endangered Wildlife In Canada (federal)
FGC	Forest Genetics Council of British Columbia (provincial)
GCTAC	Genetic Conservation Technical Advisory Council (provincial)
GRM	Genetic Resources Management
LRDW	Land and Resources Data Warehouse (provincial)
MFR	Ministry of Forests and Range (provincial)
MOE	Ministry of Environment (provincial)
MPB	Mountain pine beetle
NGO	Non-governmental organization
OGMA	Old-Growth Management Area (provincial)
RISC	Resource Inventory Standards Committee (provincial)
RMNP	Rocky Mountain National Parks (federal)
SARA	Species At Risk Act (federal)
TEM	Terrestrial Ecosystem Mapping (follows provincial standards)
TSC	Tree Seed Centre (managed by MFR)
USDA	United States Department of Agriculture (federal)
WBP	Whitebark pine
WHA	Wildlife Habitat Area (provincial)
WPBR	White pine blister rust

Objective

To develop a comprehensive strategy to guide whitebark pine (*Pinus albicaulis*) genetic conservation and prioritize activities in British Columbia under the auspices of the Genetic Conservation Technical Advisory Committee that will support the initiatives of other agencies working on whitebark pine conservation.

Preface

This document aims to specifically address the genetic component of whitebark pine conservation in BC. It can be adopted to support a wider conservation and restoration strategy, and could also apply to Alberta populations. This strategy will be reviewed approximately every 3 years to accommodate emerging knowledge and changes in the circumstances and status of whitebark pine.

This strategy is developed under the auspices of the Genetic Conservation Technical Advisory Committee (GCTAC). While its mandate and capacity do not encompass all of the proposed activities, we support this strategy and its components in principle, and encourage other agencies or groups to undertake specific activities aimed at implementing this strategy. Those interested in doing so should contact GCTAC and we will provide expertise and support where that is feasible, which will be assessed on a case-by-case basis. To promote collaboration and advance conservation of this threatened species, GCTAC welcomes expressions of interest and urges interested parties to keep in touch about activities associated with this strategy.

Contact information:
Dave Kolotelo, Chair Dave.Kolotelo@gov.bc.ca 604-541-1683 ext 2228
Jodie Krakowski, jodie.krakowski@gov.bc.ca 250-749-6811 ext 43

Background

Over the past 25 years, researchers in the U.S. Intermountain and Inland Empire Regions have noted rapid mortality in whitebark pine populations (Keane and Arno 1993; Keane et al. 1994). Concerned over its high susceptibility to white pine blister rust and mountain pine beetle, coupled with detrimental impacts of the aggressive U.S. fire suppression program, researchers initiated a wide range of studies and forums to gather and share new information. It became apparent that whitebark pine, a relatively widespread subalpine species throughout western North America, was experiencing very severe and recent declines, especially in the Rocky Mountains around Yellowstone, Idaho, and Montana, caused by white pine blister rust (Kendall and Keane 2001).

The USDA Forest Service has made major advances in whitebark pine research to track previous responses to climatic change and disturbance regimes, ecosystem modelling, and implementing and monitoring restoration initiatives (Hallett and Walker 2000; Perkins 2001). Over the past decade they have also developed operational whitebark pine rust resistance assessment, building on the infrastructure and methodology of their highly successful white pine blister rust testing and screening programs for western white pine (*P. monticola*) and sugar pine (*P. lambertiana*). Thousands of trees from hundreds of families have been screened using controlled inoculations, and seedlings are periodically assessed in the field to determine the nature and inheritance of rust resistance mechanisms (Mahalovich et al. 2006; Sniezko 2006). Over a hundred families have already been selected for heritable rust resistance (Shoettle and Sniezko 2007), although none to date have found the single-gene resistance characterized for some pines in the related subsection Strobus (Vogler et al. 2006). The results have been used to develop ecosystem restoration and seed transfer guidelines for whitebark pine, prioritize future research (Mahalovich and Dickerson 2004; Aubry et al. 2008), and implement and monitor restoration activities.

In Canada, particularly in British Columbia which contains most of the species' range, naturalists, the BC Forest Service, Parks Canada, and universities continue to evaluate the status and factors affecting whitebark pine populations in Canada (Figure 1). Parks Canada initiated studies centred on the Rocky Mountain National Parks, and began to implement and study several restoration projects, including controlled burning and planting (Wilson and Stuart-Smith 2001). Licensees and operational foresters have supported retaining whitebark pine trees and in wildlife tree patches instead of being harvested with adjacent lodgepole pine.

Figure 1. Whitebark pine current range in B.C. (from Campbell 2008).

Genecology studies have made recommendations for seed transfer in Canada and the U.S. (Mahalovich et al. 2006; Bower and Aitken 2008). Collaborations have resulted in sharing of both information and seeds. Meetings and conferences have provided forums for exchanging information and ideas between agencies and jurisdictions.

Whitebark pine conservation strategies and priorities have been developed for specific regions (e.g., Greater Yellowstone Area Working Group Whitebark Pine Cooperative; Wilson and Stuart-Smith 2001; Aubry et al. 2008; Burns et al. 2008). This approach has resulted in local successes, but there is still a need to integrate across jurisdictions to fully grasp the extent of the problem, and share resources to mitigate it. Most agencies acknowledge genetic conservation is a fundamental component of long-term conservation of whitebark pine populations and ecosystems. The Genetic Conservation Technical Advisory Committee of the Forest Genetics Council has developed a framework identifying key priorities and issues for whitebark pine genetic conservation across BC. This framework could be extended to Alberta, the USA, and incorporated into a broader conservation strategy for the species.

Scoping

This document is not a comprehensive summary of the literature. Conservation strategies and information specific to whitebark pine were reviewed with respect to their applicability to a BC-wide conservation framework. Some data and objectives are only pertinent to specific areas or land tenures, while others were more widely applicable. Options were reviewed for urgency, feasibility, cost, likelihood of success over the shorter and longer terms, and likely candidates for achieving particular objectives.

Mandate and supporting guidance

The objective of this strategy supports the responsibility of the MFR to act as a steward for the forest resources under the *Ministry of Forests and Range Act*.

In 2007 and 2008, a scoping exercise to refine and clarify the priorities of genetic resources management (GRM) in B.C. was conducted (Sutherland 2008). The need to explicitly address biodiversity and genetic conservation, adapting to climate change, evaluate the efficacy and impacts of new technologies, and meet our international protocol obligations were all identified as key drivers of contemporary GRM. The focal components of conservation and resilience would be applied to non-commercial species. Guidance for the 2009-2014 FGC Strategic Plan (in development) should consider resources of commercial and non-commercial species, and consider values on forested and non-forested lands, protected areas, private lands, and Crown lands. Strategies and impacts are to be considered over a range of timeframes. The Guiding Principles of the GRM Challenge Dialogue (Sutherland 2008) support this strategy by identifying collaboration, use of current science to guide and monitor decisions, and proactively address developing issues and technologies. Core Business Objective 6.1.1 specifies conserving the genetic diversity of representative populations of all B.C. tree species. Objective 6.2.4 recommends prioritizing and filling knowledge gaps based on research. Other objectives also have relevant elements, including communications and applying current research to guide decision making.

This includes the associated genetic resources of the province, as a component of science-based forest genetic resources management, as identified by the Forest Genetics Council Strategic Plan (FGC 2004). In particular, the goal of the Strategic plan is to "lead the cooperative management of tree gene resources in British Columbia consistent with scientific and conservation principles." Specific activities relevant to this conservation strategy include Objective 3: "support gene conservation research and the cataloguing of indigenous-tree genetic resources," and Objective 5: "monitor progress in gene resource management activities." The mandate of collaboration is described in Objective 4: "coordinate stakeholder activities and secure resources to meet Business Plan priorities."

The FCG and GCTAC drafted the document *Indigenous-Tree Genetic Conservation in British Columbia* (Kolotelo et al. 2007), which further outlines priorities specific to this strategy while supporting the existing framework including the Chief Forester's Stewardship Vision. Gaps identified in that strategy can be filled here with respect to whitebark pine by securing partnerships. Operational genetic conservation activities, cross-agency communications, improving accuracy inventory, and enhancing the representation and long-term efficacy of *in situ* reserves all can be supported through this strategy. Using knowledge of the natural patterns of diversity to guide conservation efforts was identified as Performance Measure 2. MFR is advancing its recommended roles in the identified activities, but capacity is limited and securing partner commitments remains an area for improvement.

Key Goals

Key goals for timely support of whitebark pine genetic conservation are identified and presented here roughly in order of priority. For each, specific objectives and major challenges are identified. In the Discussion, each goal is explored in terms of current knowledge and status, prospective partner agencies, and other factors.

1. ***Ex situ conservation***

Objectives:

a. Permanently identify, spatially reference, and collect seed from WPBR-resistant and MPB-resistant individuals and populations in all seed zones. Use single-family collections.

b. Prioritize MPB-affected stands.

c. Research optimal storage methods to preserve long-term viability; store seed by family.

Challenges:

I. Re-locating trees identified as putatively resistant in earlier studies, targeting severely impacted stands rather than disease-free or MBP-free areas. Tag and GPS trees wherever possible, maintaining accurate and accessible records.

II. Recent studies show trees with blister rust are preferentially attacked by MPB, eliminating potentially rust-resistant genotypes.

III. Populations in some heavily rust- and beetle-affected areas are being extirpated so *ex situ* collections may be their only means of conservation.

IV. Non-destructive seed collection of whitebark pine is costly and time consuming; cone crop periodicity necessitates opportunistic collections and funding flexibility. Consider helicopter-access collections and tree climbers in taller stands for wider collections.

2. ***Collaboration and extension***

Objectives:

a. Work with government agencies, individuals, naturalist groups, NGOs, First Nations, and licensees to promote awareness and conservation measures.

b. Regular reporting of initiatives and results on web sites – each agency reports; there could also be a central website with links to partner agencies.

c. Enhance linkages with regional silviculture (e.g., SISCO), Whitebark Pine Ecosystem Foundation, RustBusters, IUFRO Five-Needle Pine Working Group, IUFRO High-Elevation/Montane Ecosystems, and other relevant workshops/meetings.

Challenges:

I. Resource allocation and prioritization for extension.

II. Ensuring partners stay involved and follow up on initiatives.

3. ***Screening for blister rust resistance***

Objectives:

a. Quantify the distribution of resistance levels and mechanisms throughout natural populations.

b. Screen phenotypically resistant families to select individuals as candidates for seed collection for restoration and *ex situ* conservation.

Challenges:

I. Current capacity shortfall in BC necessitates screening be conducted at USDA facilities.

II. Ensuring clear objectives for lots to be screened and rigorous statistical design to prevent confounding factors (e.g., different results across facilities or years), or lack of statistical power to guide decisions.

4. ***In situ conservation: sustain the diversity of natural populations and their habitats over the long term***

Objectives:

a. Preserve the genetic diversity among and within populations.

b. Ensure well-adapted genotypes are maintained across the landscape in a variety of protected areas.

c. Establish natural seed production areas of phenotypically resistant genotypes in suitable sites for a long-term strategy.

Challenges:

I. Develop an approach to prioritizing areas: by likelihood of success (e.g., MOE Conservation Framework approach) or by rarity/uniqueness/urgency of threat (e.g., most other schemes).

II. Determining how well adapted and how differentiated marginal and isolated populations are.

III. Future suitable habitat: much of its current range may become unsuitable with projected climate change. Depending on natural disturbance regimes, rust and MPB, it will be outcompeted by other species in many habitats. Assisted migration is costly and uncertain; it will likely take several decades to determine outcomes and impacts on other ecosystem components (e.g., birds may disperse to suitable sites 1-10 km away on average).

5. ***Assemble inventory of whitebark pine populations to ensure representation of the genetic diversity in B.C.***

Objective:

a. Update or compile inventories of whitebark pine populations and health status at a scale suitable to guide planning and conservation.

Challenges:

I. Resource inventories of these ecosystems are typically lacking or inaccurate.

II. Inventory databases inside and outside of parks are not harmonized, and often not standardized across parks.

III. Information on status of various populations with respect to mountain pine beetle (MPB) and blister rust mortality is patchy or coarse-scale.

Partner Agencies

Key potential partner groups that can support the whitebark pine conservation framework in identified areas of expertise are in Table 1.

Table 1. Potential partner agencies and areas of activity; those specifically supporting whitebark pine conservation have an asterisk.

Agency	Department	Focus area
Government: federal	Parks Canada	• Implement conservation strategy in National Parks* • Park inventories and health status of WBP* • gather data on projects in National Parks* • providing information to park users
	Canadian Forest Service: Pacific Forestry Centre	• Pathology support: forest health data, identifying resistant trees, populations of interest, resistance mechanisms, monitoring, extension* • Entomology support: MPB monitoring and identifying resistant trees, research, extension*
	COSEWIC	• Consider factors to support federal listing under SARA*
Government: provincial	MFR: Stewardship Div	• Research and monitoring* • Genetic conservation: *ex situ* activities and coordinating/supporting *in situ* activities* • Population and quantitative genetics including support for WPBR resistance screening and testing*
	MFR: Regions	• Support inventory and monitoring, where possible* • Pathology support: forest health data, identifying resistant trees, populations of interest, resistance mechanisms, monitoring, extension* • Entomology support: MPB monitoring and identifying resistant trees, research, extension*
	MFR: Ops Div & Districts	• Establishing operational guidelines by region/district* • Support cone collection and reconnaissance, where possible* • Extension and information sharing with licensees
	MOE: CDC	• Evaluation for provincial listing of species and ecosystems (endangered in AB, special concern in BC)*
	MOE: Env Stewardship Div	• Establishing WHAs/OGMAs and other landscape/wildlife planning
	MTSA	• Recreational areas planning, providing information to tourists and recreational users
Licensees		• Wherever possible, retain WBP to meet biodiversity objectives and support Chief Forester guidance on WBP conservation* • In stands with substantial WPB components, consider burning as a silvicultural treatment
NGOs	Conservancy groups, local government	• Acquiring WBP habitat, especially where unique populations (rust-resistant) or ecosystem types occur* • Education and protection: covenants, conservancies, etc. on recreational and scenic subalpine lands, volunteer restoration and monitoring*
	Naturalist groups, local experts	• Supporting projects on a site-specific basis • Identifying candidate populations and individuals for selection and collection* • Volunteer support for collection, restoration, and monitoring projects*

Agency	Department	Focus area
Academia	Natural resource & environmental science faculties, UBC Centre for Forest Conservation Genetics, UNBC, Selkirk College, etc.	• Research on WBP biology, genetics, conservation, management options, etc.* • Partnering with other agencies to build capacity and leveraging • Supporting monitoring projects* • Research on resistance mechanisms to WPBR, MPB
Recreational developers	Intrawest, local ski hill operators	• Facilitating access to selected populations and research sites* • Supporting conservation and restoration activities* • Extension: providing information to recreational users
First Nations		• Identification and incorporation of cultural and traditional knowledge in WBP habitat (collection/seed use)* • Providing access to collection sites*
Consultants / contractors	Yellow Point Propagation, other specialists	• Providing expertise in local areas* • Supporting capacity to achieve timely and cost-effective results (e.g., local cone collections from identified stands or trees, developing and implementing restoration activities)

Discussion

This section contains more detailed information on the considerations associated with each component of the conservation strategy. Suggested partners for various parts are described, expanding on roles identified in Table 1. Ensuring information on progress and project successes is regularly made available to the public, researchers, and partner agencies is important to secure timely support for this non-commercial species.

Timelines for achieving these objectives will depend on factors affecting each partner agency. Some items can be done in the **short term** (0-3 years), including the most urgent activities. These include seed collections and collecting seed specifically from rust-resistant trees, updating inventory, and providing surplus seed to support research and restoration strategies. **Medium-term** (3-10 years) objectives could include developing a 1:20,000 inventory database (if needed), screening populations and families for rust resistance in greenhouse and field trials, securing sufficient putatively rust-resistant seed for ongoing restoration activities, and filling in gaps of seed collections. **Long-term** objectives may incorporate establishing seed production areas and/or a seed orchard, ongoing monitoring of natural populations *in situ* for health, and continuing to support and monitor restoration initiatives by providing the appropriate information and genotypes.

1. Ex situ *conservation*

Background

Ex situ conservation plays an important role in whitebark pine conservation in BC. The primary objective of *ex situ* conservation in this context is to provide long-term conservation of viable seed from enough genotypes with important traits: particularly blister rust and MPB resistance or tolerance. While the USDA has identified a target of 25 seeds from 25 trees per collection area (of which there may be more than one in a seed zone, depending on environmental heterogeneity), MFR currently uses a threshold of 1000 seeds per seed zone as a secure collection from at least 10 unrelated individuals. Given the logistics and cost of cone collecting, the target may be lower for whitebark pine. USDA guidelines recommend screening 75-150 candidate trees to ensure 15-30 resistant individuals can be identified based on 20% natural resistance or tolerance (Aubry et al. 2008). In BC this would correspond to testing at least 50 spatially separate individuals per zone, which reflects the fewer, larger seed zones recommended for whitebark pine (Bower and Aitken 2008). Collecting seed from 50 families per population per zone (which can correspond to a BEC subzone or an identified plant association: Campbell 2008) is probably adequate to conserve population differentiation.

Given the rapid decline of whitebark pine populations and the likelihood of continuing declines due to WPBR, MPB and wildfire, **identifying phenotypically rust-resistant individuals and collecting seed from them should be a top priority for conservation** (Mahalovich et al. 2006; Aubry et al. 2008). Re-evaluating individuals identified during MFR field surveys (Zeglen 2000, 2002) would be a logical and cost-effective start: geographic coordinates are available for these stands, and it may still be possible to identify flagging or tags. Additional local information may be available to guide stand selection to locate more candidates, and aerial surveys using fixed-wing aircraft or helicopter reconnaissance can also efficiently locate surviving trees in stands with high rates of infection or mortality for both MPB and WPBR-resistant trees. The provincial and federal forest health survey data can also be used to target WBP stands for additional reconnaissance. Stands with green and red attack can be assessed for hypersensitive reactions to the MPB (Yanchuk et al. 2008). In Yellowstone NP, trees infected with WPBR were preferentially attacked by MPB (Bockino 2008). This weakening and increased attack aggregation on the host tree may obscure any potential hypersensitive response to MPB attack, causing the loss of valuable genotypes.

While seed collections would be the foundation of *ex situ* conservation for whitebark pine, they are extremely costly and logistically challenging. Stands with at least a moderate cone crop for the current year must be identified the year before or very early in the season of the current year. Without wire mesh caging (e.g., 1/4" or 1/8" hardware cloth), every cone may be partially or fully consumed by predators. As soon as the snow melts, stands must be visited and cones caged, and each tree must be documented to ensure an accurate inventory. Trees taller than approximately 20 m, and stands with very good form (single bole, straight, few to no lower branches) are extremely difficult to reach and would require professional climbers. Each cage must then be revisited in late fall and the cones harvested and cages removed, ideally without removing the cones that would mature the following year. This extremely time consuming and somewhat hazardous exercise requires at least 2 visits to each tree excluding a reconnaissance site visit, as opposed to the traditional method of cone collection: falling the tree. Helicopter collections may be an option but would likely damage individual trees, reducing their reproduction for several years, and possibly stressing them enough to increase susceptibility to MPB or WPBR. Thus, non-destructive cone collections are necessary but costly.

Flexibility in funding allocations is important to secure seed collections when available. Cone crops are periodic and irregular. The previous year's immature cones provide some indication, but funding must be available during the year and seasons when collections can be made if the cone crop is good.

After seeds are collected, prior to their utilization, they are stored at the Tree Seed Centre (TSC), a facility managed by MFR – Tree Improvement Branch. The TSC has the mandate to store operational and conservation seed collections under carefully controlled conditions, and conduct viability and germination tests following internationally standardized protocols. The provincial seed inventory is managed by the TSC, and collections stored there represent an important component of *ex situ* conservation. The TSC has restricted access, emergency/fire control devices, and power backups in place to ensure the integrity of collections. Optimizing protocols for seed processing, storage and germination also warrants further study to get the best results possible from this species, which tends to have low germination rates, immature embryos, delayed germination, and fairly high cost of extracting and processing seedlots.

M.F. Mahalovich (pers. comm.) observed that eight years is the average storage life for seed under ideal conditions. Ensuring continual replenishment as seed is tested and deployed is one more facet of *ex situ* prioritization that must be considered.

Partners

Ex situ conservation provides many opportunities for collaboration. Contractors have specialized cone collection expertise, particularly Yellow Point Propagation, which has supported whitebark pine collections and conservation for many years, as has Selkirk College. There are also opportunities to exchange surplus seed with individuals and agencies across jurisdictions. The informal network of Canadian and U.S. whitebark pine researchers has been extremely supportive of such arrangements in the past for various projects.

MFR has several staff members with expertise in whitebark pine ecology, pathology, and genetics, as well as nursery and storage facilities at their coastal and interior research stations, and the TSC, respectively. MOE has also expressed support for whitebark pine conservation. The Canadian Forest Service has staff specializing in MPB dynamics and modelling.

BC Parks and Parks Canada are essential partners in supporting this activity by issuing seed collection permits. The aesthetic challenges presented by having cages installed throughout the tourist season may be addressed through interpretive materials for visitors, or else by restricting collection sites away from trails and viewscapes. Parks staff may also facilitate identification of rust or MPB-resistant individuals based on their familiarity with their operating areas. Forest licensees can support this measure by preserving WBP in their operating areas wherever feasible, a measure supported by a letter from the Chief Forester’s office.

Summary

The main components of *ex situ* conservation for whitebark pine are identification of rust- and MPB-resistant individuals and seed collection. Seed is costly to collect, requiring multiple site visits and cone caging. Documenting collections by tree is critical, and permanently tagging or monumenting putatively resistant trees should also follow standard protocols.

2. Collaboration and extension

Background

To succeed in implementing the components of this conservation strategy, cross-agency collaboration is essential. Timely and effective communication will clarify roles and deliverables, which agency is responsible for which component, and timelines for implementing different steps. Sharing resources, allocating personnel to tasks where they would be most effective, and leveraging funding opportunities can also be significant benefits gained from collaboration. Partnerships with local NGOs and environmental groups, First Nations, and licensees can also facilitate achieving the goals identified in this strategy by facilitating access to areas of interest, fostering volunteer support, and implementing management options.

Sharing results and discussing challenges and opportunities form the main part of extension between participating agencies so each can learn from experience. However, just as important is providing extension to the public and external agencies. Engaging the public in whitebark pine genetic conservation is important to maintain transparency as well as interest and support.

There are many forms the extension can take, depending on the audience and which component of the strategy is being addressed. In parks, signage and interpretive materials along trails, at affected viewpoints, and at visitor centres can be developed. These may also include pamphlets, poster-type signage, etc. Outside of parks materials can be developed in collaboration with the landowner or tenure holder and MFR District office, and would probably be focused on visually sensitive areas. Research results can be made available on academic and government websites, summarizing key methods and results of studies that may not be accessible to the general public. Websites are an ideal forum for more detailed background information and posting some results as they become available, including links to relevant pages (e.g., Whitebark Pine Ecosystem Foundation, Silvics of North America whitebark pine page, links to research material, webcam of research site).

Finally, disseminating the results of the various initiatives will "close the loop" in this strategy. Sharing information on what has been achieved, what worked and what didn't, as well as methodological details, will aid other researchers working to achieve the same goals in other areas. For more technical research extension, ensuring the results are communicated in a way that the target audience can access and understand is important. The USDA model of freely publishing online PDF versions of posters, presentations, and summary reports to complement peer-reviewed research has had good uptake. Continuing partnerships by participating in conferences and meetings such as Rocky Mountain Whitebark Pine workshops, Whitebark Pine Ecosystem Foundation, RustBusters, IUFRO Five-Needle Pine Working Group, IUFRO High-Elevation Ecosystems Working Group, and others are the best way to achieve this across wider jurisdictions, and cross-pollinate ideas from a broad field of participants and topics.

Partners

Partners would be those mentioned previously, depending on the location of the site. MFR – Tree Improvement Branch provides specialized extension services, and has expertise in this field. Industrial partners (e.g., alpine recreational developers, forest tenure holders) should be consulted throughout the development of interpretive materials and encouraged to host links and information on their websites. Colleges and universities involved in whitebark pine projects can provide additional support and expertise. Local stewardship and volunteer groups should also be consulted and their contributions acknowledged.

Summary

Continuous collaboration and information sharing are prerequisites for the successful implementation of the whitebark pine genetic conservation strategy. Ensuring objectives and responsibilities are clear to all participants will increase the effectiveness and efficiency of the program. Developing interpretive materials for the public in key sites will contribute to engagement and support of various measures that may be aesthetically undesirable, but important components of the conservation strategy, such as cone caging or burning. Providing additional information in easily accessible web pages hosted by partner agencies, including results of the monitoring program, will also contribute to these objectives.

3. Screening for blister rust resistance

Background

There are two main information gaps that screening for rust resistance can fill: 1) quantifying patterns of resistance in natural populations, and 2) rigorously screening putatively resistant families to understand the mechanisms and heritability of resistance so backward selections in natural populations can be identified for seed collection. Each will require a different set of populations and criteria to select material for testing. Identifying the extent of natural resistance allows us to better predict outcomes *in situ*, establish a baseline to compare the outcomes of various activities (including doing nothing), and capture alleles and gene complexes that have not been influenced by blister rust selection pressure.

Screening selected individuals for rust resistance is a critical component of *ex situ* conservation, and can also support *in situ* restoration. Blister rust causes very high mortality in seedlings and young trees because of the high likelihood of a stem being girdled by the canker. For a tree to survive to reproductive maturity, the resources spent to collect seed will be far more likely to yield long-term benefits. Restoring resistant individuals across the landbase will help ensure this species will continue to provide ongoing ecosystem benefits over the long term. This may include augmenting existing populations with adapted seed and seedlings from the same seed zone since it is unnecessarily costly and time consuming to try and reforest every stand with local seed since populations throughout the region have similar genetic patterns.

The USDA Forest Service has advanced programs where putatively rust-resistant whitebark pine seedlings are grown in nurseries using standardized protocols, inoculated with spores from various species of *Ribes* which are cultivated for this purpose, and screened under controlled conditions (Mahalovich et al. 2006; Sniezko 2006). Assessments to classify resistance or tolerance mechanisms are carried out over the following years during which seedlings are outplanted in farm field trials. This enables further research on the inheritance, interactions, and genetic control of resistance. To date they have screened many thousands of seedlings from hundreds of families, and the oldest field trials are now 10 years old. This process has resulted in identification of many families with resistance (Schoettle and Sniezko 2007).

Establishing a similar facility in BC would be straightforward (Krakowski 2006), but the resources and capacity to conduct the intensive work would be challenging to secure for this non-timber species. To overcome this obstacle, the USDA tests whitebark pine along with commercial pine species as part of their white pine blister rust programs including western white, sugar, and other 5-needle pine species, incurring only incremental costs and no additional infrastructure requirement. They have the capacity to screen BC seedlots.

To avoid potential confounding effects of different facilities or years, etc., it is important to include check lots in each batch of seed sent for screening. Sufficient numbers of seed per family or population must be available (750 seeds per tree for Coeur d'Alene, 100 seedlings per family so at least 400 seeds per tree for Dorena). A good rule of thumb is to collect an extra seedlot for screening when an *ex situ* lot is collected (Shoal et al. 2008; R. Sniezko, pers. comm.) so resistance information on that seedlot can be assessed in a timely manner.

A complementary field screening program is an integral part of any artificial screening program. Results may differ, including the expression and durability of resistance mechanisms.

Partners

The USDA Forest Service Research Stations at Coeur d'Alene and Cottage Grove have expertise growing whitebark pine seedlings in an operational nursery setting (Burr et al. 2001), as well as conducting blister rust screening (Vogler et al. 2006; Krakowski 2006). They have the capacity to screen BC seedlings and have agreed to offer their services, but the cost and challenges associated with transporting infected material across the border may be restrictive. Creating and maintaining linkages with pathologists in BC and Alberta, such as participating in the screening process, would help build additional capacity.

Summary

Screening requires a multi-year commitment and support personnel to support the production of viable numbers of robust, resistant seedlings for ecosystem restoration based on the successes of the U.S. model to date. Screening can help determine the distribution and mechanisms of rust resistance in natural populations, as well as identify families with various resistance mechanisms for seed collection and propagation. Enough seed from candidate trees must be collected to meet the minimum testing requirements.

4. **In situ** *conservation: sustain the range of natural populations and their habitats over the long term*

Background

Ecological communities reflect intervals along successional pathways that vary with geography, aspect, moisture, nutrients, and disturbance history (Campbell and Antos 2000; Moody 2006; Campbell 1998, 2008). Conserving the full range of habitat types, where possible, would ensure that the conditions exist to preserve the adaptive capacity of populations. Genetic diversity within the BC populations of whitebark pine is comparable to other conifers, and populations are relatively weakly differentiated (Krakowski et al. 2003. However, studies of phenotypic variation reveal that regional adaptation does occur (e.g., Bower and Aitken 2008), so protecting populations from several regions is necessary to conserve the genetic and adaptive potential of the species.

In situ populations will form the backbone of whitebark pine conservation. For this non-commercial species that typically occurs in remote habitats, costly and unproven interventions such as facilitated migration may not be feasible solutions to sustain its presence over a large area. The large extant populations still contain a vast number of individuals, within which over 90% of the genetic diversity is contained within populations and under 10% between populations (Jorgensen and Hamrick 1997; Stuart-Smith 1998; Krakowski et al. 2003). Adaptive traits show regional differentiation (Bower and Aitken 2008), although few data are available for the BC Rockies (Mahalovich et al. 2006). Preserving the genetic diversity of whitebark pine will naturally follow if sufficient numbers of individuals from various populations are conserved.

Although whitebark pine is very well represented in protected areas such as provincial and national parks (Chourmouzis et al. in press; Table 2), it continues to decline rapidly. To alter this trajectory, more specific proactive measures will likely be needed, including restoration such as planting, thinning competing trees, and fire management. Abundant information is available to guide targeted gene conservation for the long-term persistence of the species. Putatively resistant trees and stands can be protected from MPB using pouches (tree) or flakes (aerial) of verbenone (Kegley and Gibson 2004) or other treatments. Wildland fire control or fuel management efforts can be implemented near identified stands.

For long-term population sustainability it is important to preserve gene flow via population and habitat connectivity. This can be addressed simply for most whitebark pine populations by maintaining large, contiguous tracts of mountain parks that facilitate bird dispersal (Lanner 1982; Richardson et al. 2002), as long as populations do not decline to the point where birds relocate to other habitat types (McKinney and Tomback 2007). Ensuring available habitat to support population persistence and continued environmental adaptation under climate change will likely require both active and passive management. Active management may include controlled burns or thinning other species to free up sites for whitebark pine regeneration and stand development. Passive management includes a “let-burn” policy in high-elevation ecosystems where there is no danger to human life or livelihood.

Table 2. Proportion of whitebark pine in protected areas by BEC zone (from Chourmouzis et al. *in press*).

BEC zone	Area protected (ha)	Percent of range within zone protected
AT	1,109	36.6
ESSF	17,387	23.8
ICH	5	5.2
IDF	23	44.2
MS	94	17.5
SBS	80	35.7

Given projected impacts of climatic change on these highly susceptible subalpine ecosystems (Hamann and Wang 2006), the current extent of whitebark pine ecosystems is expected to decline drastically over the medium to long term (Campbell 2008). Various community types and disturbance agents will be impacted differently by climate change. Identifying the expected impacts will identify the most vulnerable ecosystems and populations. Seed planning zones will need to be periodically re-evaluated to accommodate shifting climate envelopes. A project at UBC is assessing potential responses to assisted migration in areas inside and outside of whitebark pine current climatic suitability using directly planted treated seeds to further explore this option[1].

Based on this knowledge, the next step is to determine priorities for *in situ* resources by predicting ecosystem responses to mitigation strategies. If the likelihood of a positive outcome is low to nil, it may be more prudent to focus activities on less vulnerable ecosystems. Depending on the certainty associated with the various models, it may be wise to select a subset of all ecosystem types for adaptive management in the event the models are overly pessimistic

[1] <http://genetics.forestry.ubc.ca/cfcg/projects.html>

or optimistic. Local environmental variation (e.g., microsite, aspect, substrate) has some influence, but at a scale too small for modelling (e.g., Shoal et al. 2008). Another key unknown is the distribution of natural resistance, which may be addressed by screening a sample of populations across the range—this would take approximately 7-10 years to obtain results (Schwandt 2006).

Establishing seed production areas may also constitute one facet of *in situ* conservation over the long term. These would most likely have to be within whitebark pine habitat for optimal results, so they may be regarded as *inter situ* installations, where a collection of candidate and screened genotypes are established and assessed in a test site. This may be incorporated into the design of a research trial, such as a provenance trial. Once resistant individuals have been identified, grafts of parents and their seedlings can be established in seed production areas (which may be in the same location as the trial). Several candidate areas have been identified (D. Piggott, pers. comm.) that are relatively easy to access with gentle terrain and existing whitebark pine populations, which demonstrate their suitability to support the species with no management inputs except for cone collection. The extremely long timeframe required to produce seeds means this is currently a low priority, unless existing suitable sites and populations show resistance after screening.

Another research project has been examining biotechnology options for propagating whitebark pine, including tissue culture and somatic embryogenesis (D. Noshad, pers. comm.). To date whitebark pine has been recalcitrant, and to develop enough lines of resistant material to meet minimum genetic diversity criteria would be extremely costly. Research is continuing (S. Mansfield, pers. comm.).

Partners

National and provincial parks and conservancies will be the primary sites implementing whitebark pine conservation measures, and therefore agencies responsible for parks will bear the responsibility for most of these activities. If unique populations or rare community types are observed on a commercial tenure, the licensee may be amenable to supporting some measures such as setting aside a stand of whitebark pine. Additional landscape and habitat modelling research on whitebark pine ecosystems may be conducted by universities and government (Parks Canada, Natural Resources Canada, MFR – Research Branch). Regional pathologists and local naturalists may also be aware of unique stands or populations.

In national parks, Parks Canada would be the key agency; in conservancies and provincial parks, the Ministry of Environment, Environmental Stewardship Division and BC Parks would be leading agencies. First Nations who co-manage conservancies and protected areas with whitebark pine may also be partners. MOE would be responsible for establishing WHAs or OGMAs in whitebark pine habitat. Area licensees should be consulted to obtain inventory information and discuss options for managing their tenure to preserve and enhance whitebark pine habitat. MFR Regional and District Managers can distribute the MFR extension bulletin promoting whitebark pine retention and conservation[2]. Local user groups (e.g., Valhalla Wilderness Society) and naturalist clubs may also be interested in identifying putatively resistant trees, collecting cones, and helping plant seed or seedlings.

[2] <http://www.for.gov.bc.ca/hti/whitebark/WhitebarkPine_Bulletin-July08.pdf>

Research conducted by universities, parks, and government agencies will continue to provide key information to guide genetic conservation. For example, the UBC Centre for Forest Conservation Genetics has funded a number of graduate student projects on whitebark pine, and continues to advance modelling of current and future species distributions and climate models. The Canadian Forest Service and MFR have supported forest health monitoring. Parks conducts ecological monitoring and gathering key baseline data. Parks monitoring or field staff can be trained to identify and georeference trees resistant to MPB or WBPR if they are surveying in whitebark pine habitat. Fire crews can be notified of the location if a putatively resistant tree is mapped in their area. District Managers can notify licensees where putatively resistant trees are found in their operating areas.

Summary

Maintaining a large enough number of surviving individuals and populations from diverse habitats in protected areas is the best way to ensure the genetic diversity of the species persists. *In situ* conservation is the foundation for whitebark pine conservation due to economic factors and logistics, especially the long generation time. Partnerships among agencies administering parks, licensees operating in whitebark pine habitat, and academia can support this objective by gathering ecosystem information, identifying populations of interest, and implementing measures to conserve and enhance habitat suitability.

5. Standardize, improve, and monitor inventory of whitebark pine populations

Background

Resource inventories covering the BC land base have been developed to classify productive timber stands, and are not typically well characterized for areas that do not support commercial forests. These areas are often inaccessible, and there may be no local knowledge of whitebark pine populations in some remote areas, exemplified from the very large isolated population near Fort St. James that was only recently documented (D. Pigott, pers. comm.). This area had whitebark pine mapped as either lodgepole pine in the older forest cover data or subalpine fir using the current VRI (J. Vinnedge, pers. comm.); such errors are relatively widespread due to the limited ground plots in whitebark pine habitat, and extensive use of air photos or satellite imagery for inventory. Wilson and Stuart-Smith (1999) updated the Ecological Land Classification for the Rocky Mountain National Parks (Holland and Coen 1993), enhancing its accuracy and utility for whitebark pine inventory and management. Whitebark pine is covered by a mosaic of varying quality: air photos, orthophotos, satellite imagery and remote sensing data, forest cover/Vegetation Resource Inventory, and biogeoclimatic plot data, and individual park inventories.

Local expertise will help identify easily accessible and outlying populations, and broader inventory data will be most useful for exploratory ground truthing. The rapid spread of both mountain pine beetle and white pine blister rust also needs to be incorporated into considerations of stands of potential interest and inventory data sets. This is already done at a moderate to coarse scale by the provincial forest health surveys (e.g., Westfall and Ebata 2007; MFR Mountain Pine Beetle Impact Mapping project[3]). Some projects, such as TEM (Terrestrial

[3] <http://www.for.gov.bc.ca/hts/rs/mpb_impact.html>

Ecosystem Mapping) and VRI (Vegetation Resources Inventory) include data fields for disturbance and forest health. Data for projects that meet data and mapping standards is available through LRDW. MFR District staff and Regional pathologists often have local knowledge on whitebark pine inventory and health.

Partners

The major stakeholder responsible for collecting and standardizing landscape inventories is the provincial government, particularly the Ministry of Forests and Range Forest Regions, and the Integrated Land Management Bureau, which is the custodian of inventory databases stored at the Land and Resources Data Warehouse. Regional pathologists and entomologists could add a wealth of empirical expertise on putatively resistant trees or stands. Additional information or data layers from MFR District staff may fill gaps at the local and regional levels. Parks Canada and BC Parks (MOE) also gather inventory data but there is no standardized inventory format across parks, so data must be converted or migrated to provincial standards wherever possible. Some areas, typically regional districts or local governments, have also gathered SEI (sensitive ecosystem inventory) or TEM (terrestrial ecosystem mapping) data, which could also be incorporated and is freely available for publicly funded projects that meet RISC standards. VRI data in areas outside of parks may be held by licensees, and data sharing agreements may be arranged for areas of interest, with their co-operation. Updating layers to reflect recent disturbance (e.g., wildfires, MPB outbreak, harvesting) can be done once the various GIS layers are assembled and integrated.

Flying and mapping air photos (or heads-up digitized photos) to an agreed set of standards (ideally RISC, but a subset of key fields can be identified to save costs) can be done by government agencies or consultants, depending on resources and capacity. Remote sensing data can also be incorporated. Inventory data from licensees in TFLs may be obtained under agreement.

Summary

An accurate and current inventory of whitebark pine occurrence and health status is a key prerequisite to directing scarce resources to identify and reduce the impacts of successional replacement, WPBR and MPB on whitebark pine. A range of options are available to integrate and update the patchwork of existing information, which will depend on the capacity of partner agencies. Simply compiling existing data may be sufficient for regional and local applications. For stand-specific measures, more detailed work is necessary; this is best handled by regional agencies gathering a standardized set of parameters that can be collated.

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