Poster 12 Partnerships in the Pacific Northwest to Help Save an Endangered Species, Whitebark Pine (*Pinus albicaulis*)—Research, Rust Resistance, and Restoration

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SUMMARY

Whitebark pine (*Pinus albicaulis*) is a keystone species that is distributed widely at high elevations across western North America (Tomback and Achuff 2010). Whitebark pine faces many threats, including white pine blister rust caused by the

non-native pathogen *Cronartium ribicola*, mountain pine beetle (*Dendroctonus ponderosae*) predation, climate change, and altered fire regimes (Loehman et al. 2011; Leirfallom et al. 2015). Whitebark pine is listed as Endangered on the IUCN Red List (Mahalovich and Stritch 2013). It is also a federally listed endangered species in Canada under the *Species at Risk Act* and has been proposed for listing under the *Endangered Species Act* in the United States. A concerted effort is needed to reverse the decline of this keystone species and enhance opportunities for its retention as a viable component of high-elevation forest ecosystems. The National Whitebark Pine Restoration Plan[1] is a collaborative partnership among American Forests, the Whitebark Pine Ecosystem Foundation, and the Washington office of the U.S. Department of Agriculture Forest Service that is guiding an inter-agency, range-wide strategic approach to restoring whitebark pine. However, a strategic plan depends on appropriate tools and techniques to build resilient whitebark pine populations (e.g., Keane et al. 2012). In the Pacific Northwest portion of the whitebark pine range, partnerships among organizations and land managers are essential to understand the current status of the species, undertake research to understand its biology (including patterns of genetic variation and resistance to white pine blister rust and mountain pine beetle), develop populations of parent trees with durable genetic resistance to white pine blister rust for each seed zone to use for seed collection to produce seedlings for restoration, provide conservation education, and implement restoration. Integrating these efforts will maximize the potential for successful retention of whitebark pine ecosystems into the future.

A U.S. Department of Agriculture Forest Service regional information survey on the status of whitebark pine in Oregon and Washington that was conducted in the early 1990s highlighted concerns about the future viability of populations of whitebark pine in the Pacific Northwest (Sniezko et al. 1994). Screening seedling families for genetic resistance to white pine blister rust began in 2002. Subsequently, an initial regional restoration plan was developed for U.S. Department of Agriculture Forest Service lands (Aubry et al. 2008). Information needs and recommendations were further delineated in a report commissioned by the Western Wildland Environmental Threat Assessment Center (Tomback and Sniezko 2017). Concerns about the effects of the biotic and abiotic threats to whitebark pine in the Pacific Northwest have led to ongoing cooperative efforts between federal, tribal, state, provincial, university, non-profit, and private groups, notably in studying genetic variation, screening for white pine blister rust resistance, and gene conservation activities (see below for some activities by various groups) (Figures 1 and 2). These efforts have helped with a broad range of initiatives: gathering on-the-ground information on the status of whitebark pine populations, beginning parent tree seed collections to use for testing more than 1300 seedling families for genetic resistance to white pine blister rust (Sniezko et al. 2007, 2011, 2018; Murray and Berger 2018; Savin et al. 2018), and initiating investigations into genetic variation and disease resistance (Hamlin et al. 2012; Gruhn 2016; Syring et al. 2016; Liu et al. 2016, 2017; Bair 2017; Beck and Sniezko 2018; Bennett et al. 2018; Cartwright 2018; Lea et al. 2018). Other applications include examining the possibilities and considerations for the use of biotechnology (National Academies of Sciences, Engineering, and Medicine 2019), gathering seed and information to aid ex situ conservation (Sniezko et al. 2017), and undertaking studies regarding endophytic microbial communities associated with whitebark

1 https://whitebarkfound.org/our-work/national-whitebark-pine-restoration-plan/.

pine (Bullington et al. 2018; Moler and Aho 2018). Partners have begun grafting to develop seed orchards of resistant parents, establish provenance trials and white pine blister rust resistance field trials and conservation plantings (Cartwright 2018; Omdal et al. 2018), and initiate the first restoration plantings (Figure 1). With the cooperation of this diverse group of land managers, scientists, forest health specialists, resource professionals, and concerned non-profit organizations, in conjunction with regional and national restoration plans, the groundwork to begin successful restoration of whitebark pine has been laid (Figure 3).

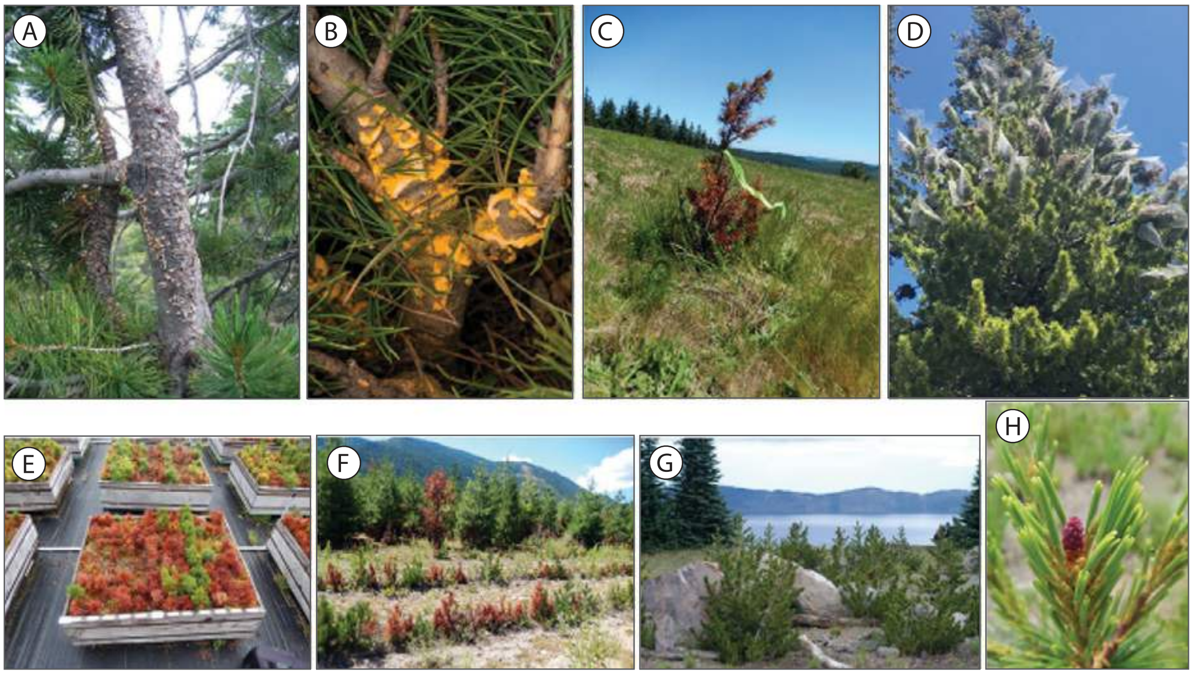

FIGURE 1 *(A) Whitebark pine at Crater Lake National Park infected with white pine blister rust; aecia present on main bole; (B) whitebark pine infected with white pine blister rust (WPBR), showing aecia present; (C) seedling progeny of Crater Lake National Park parent tree CL28, with white pine blister rust canker at the low-elevation field trial at Bureau of Land Management Tyrrell orchard, Oregon; (D) elite tree selection on Tyee Mountain (Entiat Ranger District, Okanogan–Wenatchee National Forest in Washington) from the 2018 cone collection, showing 128 cages with three to four cones per cluster; (E) white pine blister rust SY2016 resistance inoculation trial showing seedling family variation (by row) in resistance to white pine blister rust, with seedlings from the Deschutes National Forest parent tree 011192 showing very high survival; (F) whitebark pine provenance disease resistance trial at Skimikin Seed Orchard site, British Columbia, where whitebark pine was planted at a low-elevation site with an adjacent western white pine trial and infected* Ribes *spp. plants (the alternate host for white pine blister rust fungus) nearby; (G) whitebark pine restoration planting at Rim Village, Crater Lake National Park; (H) the first seed cone from one of the seedlings planted for restoration at Crater Lake National Park (photo credits: Richard Sniezko [A, C, E, F, G, H], Iain Reid [B], Eireann Pederson [D]).*

FIGURE 2 *(A) Whitebark pine cone collection on the McKenzie Pass lava fields; (B) measuring seedlings in Crater Lake National Park Horse Trail endophyte trial; (C) parent tree 011192, Deschutes National Forest of sow #54 in SY2016 whitebark pine trial, which shows one of the highest survival rates of its progeny of any of the 1300 families tested in rust screening trials at Dorena Genetic Resource Center; (D) Michael Murray demonstrating placing protection bags over conelets at Crater Lake National Park; (E) planting a seedling for restoration in 2016 at Crater Lake National Park; (F) Washington Department of Natural Resources staff planting whitebark pine on Darland Mountain in Washington; (G) U.S. Forest Service Deschutes National Forest, in conjunction with Mount Bachelor Ski Area, planting approximately 100 seedling progeny of resistant parent trees in 2019 (photo credits: Chris Jensen [A, C], Jennifer Hooke [E], Dan Omdal [F], Matt Horning [G], Richard Sniezko [B, D]).*

FIGURE 3 *Components of whitebark pine (WBP) biology, management, and restoration that will help maximize the potential for success in retaining whitebark pine in Pacific Northwest ecosystems (WPBR: white pine blister rust).*

GROUPS WORKING WITH WHITEBARK PINE IN THE PACIFIC NORTHWEST (NOT A COMPREHENSIVE LIST):

U.S. Department of Agriculture Forest Service helps coordinate and support efforts among geneticists, plant pathologists, entomologists, botanists, foresters, and silviculturists to develop populations of white pine blister rust–resistant whitebark pine for restoration. Efforts involve field surveys to monitor the current status of whitebark pine; seed collection for genetic conservation across 15 national forests, as well as national parks, and tribal lands; and cone collection from more than 1300 parent trees for white pine blister rust resistance testing at Dorena Genetic Resource Center (Figure 1E). Seeds from parent trees that are rated resistant to white pine blister rust are collected for gene conservation and future restoration (Figures 1 and 2). Many of these white pine blister rust–resistant parents or their progeny are also being grafted to place into orchards or clone banks for gene conservation and future seed production. Restoration plantings using white pine blister rust–resistant seedlots have begun.

U.S. Department of the Interior National Park Service: Six restoration plantings have been established in Crater Lake National Park since 2009 using seed from white pine blister rust–resistant trees (Figure 1G), and seed from 126 parent trees has been collected for rust resistance testing and genetic conservation. The seedlings in the restoration are identified by parent tree origin to also serve as a genetic trial. Rust-resistant trees are monitored annually and are protected from mountain pine beetle. In Mount Rainier National Park, trees have been selected and cones have been collected for white pine blister rust resistance testing, the first restoration plantings with seedling families of white pine blister rust–resistant trees have been established, and measurements are made of permanent whitebark pine health transects across the park (Rochefort et al. 2018). In North Cascades National Park, trees have been selected and cones have been collected for white pine blister rust resistance testing, and permanent whitebark pine health transects have been established across the park (Rochefort et al. 2018).

Canadian Forest Service is using genetics research tools to study genetic variation in whitebark pine and to further understand resistance to white pine blister rust (Liu et al. 2016, 2017), and is leveraging transcriptomics to identify genes associated with blister rust resistance.

British Columbia Ministry of Forests, Lands, Natural Resource Operations and Rural Development has established field trials at eight sites, three nursery bed locations, and four small tests to assess white pine blister rust resistance and other traits. Together, these trials include more than 600 parent trees and families from populations that represent much of the whitebark pine's range.

Bureau of Land Management has provided a site for two whitebark pine trials, which allows for the study of the species in a low-elevation environment and the evaluation of the seedling families for field resistance to white pine blister rust, and provides opportunities for conservation education.

Hoyt Arboretum has joined efforts in ex situ genetic conservation, and offers opportunities for conservation education, research, and restoration.

American Public Gardens Association supports the dispersal of whitebark pine seedlings from the U.S. Department of Agriculture Forest Service Dorena Genetic Resource Center to public gardens and arboreta around the country. The Association produces and distributes outreach and education materials, including a series of youth education materials on white pine blister rust and its effects on *Pinus albicaulis* as part of the Plant Heroes program.

American Forests is a long-time partner in the whitebark pine restoration effort. Since 1990, American Forests has partnered with the U.S. Department of Agriculture Forest Service to plant 500 000 whitebark pine trees across more than

809 ha (2000 acres) in the United States and Canada—this is 40% of all whitebark pine restoration since 2006. The organization also provided significant funding for the 2018 whitebark pine cone collections in Oregon and Washington. The agreement between the U.S. Department of Agriculture Forest Service and American Forests, and resulting funding in 2018, were essential in making it a successful year for cone collection in this relatively rare bumper cone crop and providing seed for the ensuing restoration efforts over the next few years. American Forests is a key partner in the implementation of the National Whitebark Pine Restoration Plan.

Whitebark Pine Ecosystem Foundation is a leader in championing whitebark pine restoration and partnering with federal agencies on related projects. Outreach, education, and information sharing has been accomplished through newsletters, community activities, annual workshops, and major conferences that bring together the scientific and management community. The Foundation is the science lead in the National Whitebark Pine Restoration Plan.

University of British Columbia is testing the potential of assisted migration and direct seeding of whitebark pine by re-assessing eight common gardens planted up to 800 km north of the current whitebark pine northern range limit. The University is also phenotyping seedlings (217 families, 46 populations) for white pine blister rust to examine variation in rust resistance and climate variables related to growth and rust resistance at parent tree locations.

Ohio State University is developing a tool for predicting white pine blister rust resistance based on spectroscopy analysis of whitebark pine needles.

Idaho State University has conducted research on the fungal ecology of whitebark pine phyllospheres in the southern Cascades, including changes in the composition of whitebark pine fungal phyllospheres following a controlled inoculation of whitebark pine with a putative fungal antagonist of *Cronartium ribicola* (Moler 2015; Moler and Aho 2018).

Washington University has conducted research on genetic variation in whitebark pine, such as the PhD thesis Ecological and Genetic Consequences of Climate Change Impacting Species Distributions, with Specific Cases in Whitebark Pine (*Pinus albicaulis* Engelm.) (Gruhn 2016).

MPG Ranch has collaborated with U.S. Department of Agriculture Forest Service to investigate the influence of genetics, defensive chemistry, and the fungal microbiome on disease outcome in whitebark pine trees (Bullington et al. 2018).

Yakama Nation is collaborating with the U.S. Department of Agriculture Forest Service Forest Health Protection group to study whitebark pine population status and collect seed for resistance testing at Dorena Genetic Resource Center. Restoration and gene conservation are proceeding via matching funds provided by the Yakama Nation and a Forest Health Protection grant received in 2016.

Colville Confederated Tribes are currently testing seedlots from tribal land for white pine blister rust resistance; testing is being conducted at Dorena Genetic Resource Center. Plans for whitebark pine restoration in burned areas are being developed. A white pine blister rust resistance and gene conservation planting was established in 2018 in conjunction with the Washington Department of Natural Resources and Dorena Genetic Resource Center (Omdal et al. 2018).

Confederated Tribes of Warm Springs has documented white pine blister rust resistance in some of their parent trees based on testing at Dorena Genetic Resource Center, but 90% of the first selected trees were destroyed by wildfire; this emphasizes the importance of ex situ in addition to in situ conservation. Cones from additional parent trees have also been collected, and testing for white pine blister rust is underway.

Washington Department of Natural Resources and Dorena Genetic Resource Center have coordinated the establishment of four field trials for genetic conservation, white pine blister rust resistance testing, and seed production (Omdal et al. 2018).

ON THE ROAD TO SUCCESS

Tremendous progress has been made for in situ and ex situ genetic conservation efforts across the Pacific Northwest portions of the whitebark pine range. The joint efforts of the many land managers and stewards across organizational boundaries in this part of the species' range have provided opportunities to identify white pine blister rust–resistant parent trees, collect seed for long-term genetic conservation, initiate provenance trials, plant the first restoration trials, and study genomic resources. These efforts will lead to a better understanding of whitebark pine's genetic variation, including how the species may fare under challenges presented by climate change. Due to extensive white pine blister rust testing, many resistant parent trees have been documented, and the large seed collection effort in 2018 (a relatively rare excellent cone crop year) bodes well for restoration efforts and provides further candidates for white pine blister rust testing. There is already evidence of success—in 2015, the U.S. Fish and Wildlife Service downgraded the endangered species listing priority number for whitebark pine, but a final decision is slated for 2020. This was due, in part, to the increased survival and propagation of genetically resistant trees in the Pacific Northwest portion of whitebark pine's range. Continued cooperative effort across organizational boundaries will provide the best avenue for dynamic genetic conservation and retention of whitebark pine as a keystone species in forest ecosystems (Figure 3).

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