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Maintaining *Pinus Strobiformis*, a Tree Species Threatened by Climate Change and White Pine Blister Rust

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ABSTRACT

Climate change and the non-native disease white pine blister rust (WPBR) pose significant threats to the health and resilience of southwestern white pine (SWWP; *Pinus strobiformis*), native to the southwestern US and Mexico. Seed sources with adaptive traits needed to survive warmer, drier conditions and durable genetic resistance to WPBR are critical to maintaining this important species on the landscape. To facilitate this need, seedlings from across the range of SWWP were tested for resistance to WPBR at Dorena Genetic Resource Center in Oregon. Major gene and quantitative resistance were documented. Data were also used to estimate resistance levels and frequency across the range of SWWP. Scion from parent trees identified as resistant was collected and grafted into a clone bank orchard at John T. Harrington Forestry Research Center in Mora, NM. In addition, progeny identified as resistant will be grafted into a clone bank orchard at Tyrell Seed Orchard in Oregon to maintain these genetics. Seed will be collected from these orchards and resistant parent trees will be planted on the landscape. We have also established two common-garden field trials in the Southwest to validate resistance results, monitor the long-term durability of resistance, and assess adaptive traits. This work provides information critical to identifying seed sources for future planting. Current challenges include funding ongoing activities (testing, outplanting and monitoring), variable and unpredictably dry planting conditions, and mortality of original parent trees. This interdisciplinary, collaborative project includes international, academic, federal, and tribal partners.

INTRODUCTION

Climate change and invasive pathogens pose significant threats to forest health and resilience. Southwestern white pine (SWWP, *Pinus strobiformis*), native to the southwestern USA and Mexico, faces increasing pressure from hotter, drier conditions and white pine blister rust (WPBR), a disease caused by the non-native fungal pathogen *Cronartium ribicola*. Seed sources with durable genetic resistance to WPBR and the adaptive traits needed to survive warmer, drier conditions in the future are essential to sustain this species on the landscape. Inoculation trials in collaboration with Dorena Genetic Resource Center (DGRC) have shown SWWP to be highly susceptible to WPBR. However, moderately high resistance has been identified in a low percentage of families (Johnson and Sniezko 2021), with much more extensive

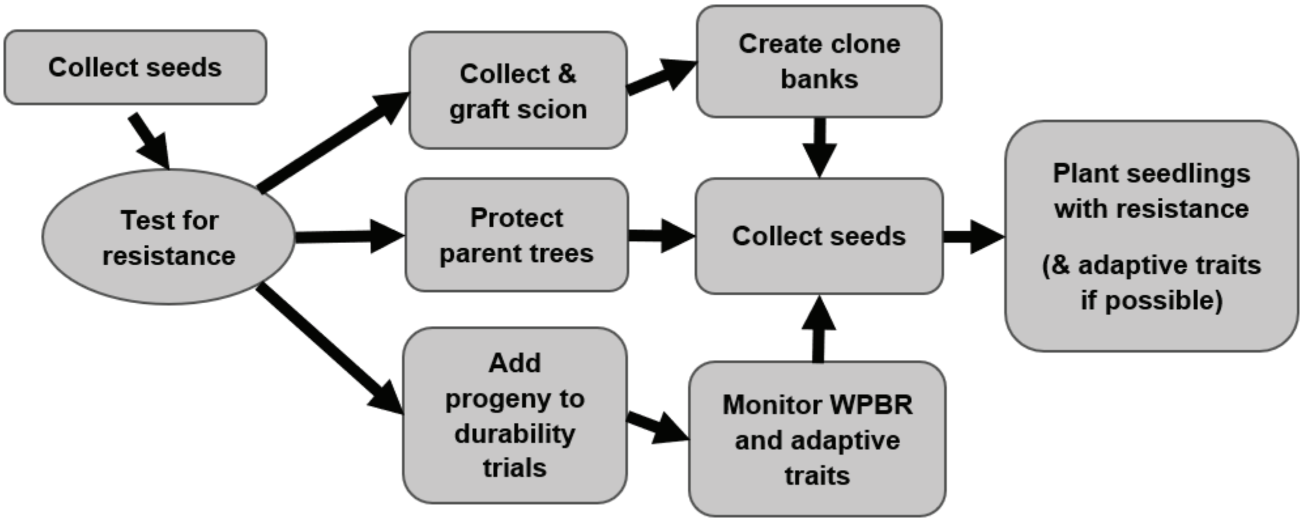

Figure 1. Flow chart demonstrating our multifaceted approach to identify and conserve seed sources with desirable adaptive traits such as drought tolerance and resistance to white pine blister rust.

testing currently in progress. We are using a multi-faceted approach to develop a collection of seed sources containing genetic resistance to WPBR and adaptive traits, such as drought tolerance, that can be used to enhance operational plantings of SWWP and increase long-term resilience in Southwest US populations (figure 1). Collaboration between Northern Arizona University (NAU), Forest Health Protection (FHP), and DRGC has produced valuable range-wide information on resistance and adaptive traits in a relatively short time span compared to other species.

SCION COLLECTIONS AND CLONE BANK

Seedlings from across the range of SWWP are currently in testing for resistance to WPBR at DGRC in Oregon. In the first trials, both major gene resistance (MGR) and quantitative resistance (QR) were documented (Johnson and Sniezko 2021; Sniezko et al. 2008; Waring et al. 2019). Scion material was collected from parent trees whose progeny were identified at DGRC as having MGR or QR to WPBR (figure 2A). Scion collections have thus far occurred in New Mexico on the Sacramento Mountains, Lincoln National Forest (2015, 2016, 2018) and Mescalero Apache Tribal Lands (2020); Zuni Mountains, Cibola National Forest (2018, 2019); and in Arizona on the Apache-Sitgreaves National Forests (2019, 2020). Tree climbers collected scion from branches in the upper third of resistant tree crowns to maximize future seed production. Following collection, which takes place in the winter, scion material was packed in moistened sphagnum moss and stored in a walk-in cooler until spring. It was then grafted onto rootstock that originated from a bulked SWWP seedlot (figure 2B) and eventually outplanted in a clone bank at the John T. Harrington Forestry Research Center in Mora, NM (a New Mexico State University facility) (figure 2C). This clone bank will preserve parental genotypes for WPBR resistance in SWWP, even if parent trees are lost to the increasingly high risk of wildfire. Collections will continue as data are analyzed and new resistant parent trees are identified. Resistant seed collected from parent trees in the field or the clone bank will eventually be provided to various partners.

PROGENY CLONE BANK AT TYRELL SEED ORCHARD

Progeny, including those which have shown resistance, are generally removed to make room for active trials following inoculation and resistance assessments at DGRC. Region 3 Forest Health Protection and NAU are collaborating with DGRC and the Bureau of Land Management (BLM) to establish a clone bank/seed orchard at BLM's Tyrell Seed Orchard to preserve progeny that have demonstrated resistance. Establishing this clone bank will enable conservation of these valuable genotypes without transporting material inoculated in Oregon to the Southwest and risking the introduction of new races of the WPBR pathogen. To date, 102 grafts representing 38 families from sow years 2002 and 2009 have been grafted and are scheduled to be planted in early 2022. Grafting will continue as trials are completed for sow years 2014, 2016, 2017, and 2020. All individuals grafted remained healthy throughout the inoculation trials, demonstrating either complete (MGR) or partial resistance (QR) (figure 3).

LONG-TERM FIELD TRIALS

Long-term field trials are used to further validate seedling assessment results from DRGC and monitor the durability of resistance. Field trials also expose trees to local site conditions and stressors which may influence susceptibility to WPBR and provide valuable information on variation in adaptive traits, such as drought tolerance. In Region 3, two field trials have been established in cooperation with the Mescalero Apache (2017) in New Mexico and the Apache-Sitgreaves National Forests (2018) in Arizona (figure 4). Both sites were established in areas currently infected by WPBR. However, no WPBR infection has been observed on either site thus far.

In Arizona, 1,092 seedlings originating from 21 open-pollinated half-sib families were planted in 2019. Due largely to hot and dry planting conditions, 40% mortality was observed the year following planting (figure 5). A second round of planting, consisting of 1,200 trees representing 57 families, including families from Mexico, was completed amid much more favorable conditions in 2021.

In New Mexico, 231 trees representing 61 families were planted in 2017. Due to harsh conditions, including a flood event following planting, 37% mortality was observed the following year (figure 6). Significant mortality has continued to occur in subsequent years. An additional 1,160 seedlings representing 56 families, including families from Mexico, were planted in 2021. Planting conditions again presented challenges as heavy rains created saturated soil conditions at the site during planting and pocket gopher activity was evident across much of the site.

CHALLENGES AND REWARDS

Establishing and maintaining a program to identify and preserve well adapted genotypes that are resistant to WPBR presents many challenges and rewards. Mortality of known resistant parent trees due to fire, insects/disease, and other abiotic stressors is a constant challenge and demonstrates the urgency and importance of scion and seed collection from these trees. Grafting has presented a challenge as many grafts are unsuccessful for various reasons, including difficulty locating scion of suitable size (around 10 mm minimum) on some parent trees. The long-term durability of field site plantings has presented many challenges, mainly related to weather conditions, which are increasingly unpredictable. In

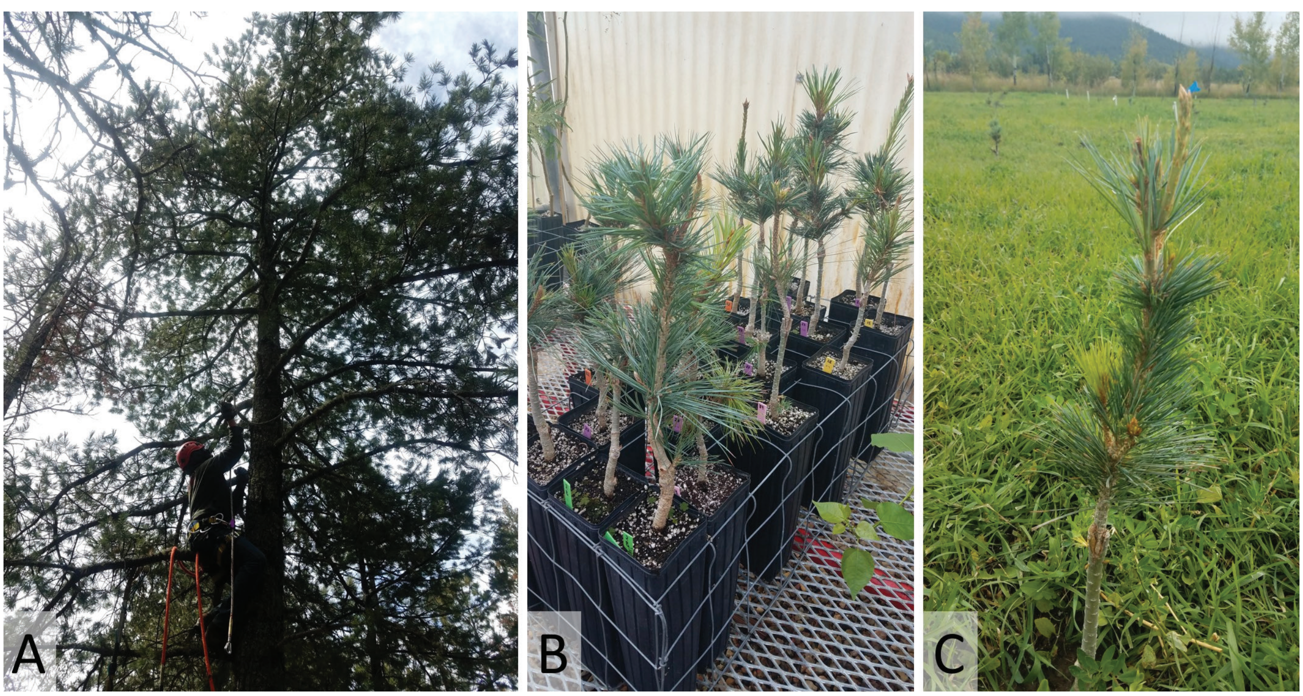

Figure 2. A tree climber collecting scion material (A), grafted scion in the greenhouse (B), and an out-planted graft (C).

Figure 3. Surviving southwestern white pine seedlings in 2021 that had been inoculated with *Cronartium ribicola* in 2010 from the SY2009 trial at Dorena Genetic Resource Center (DGRC) (A) and grafts from the SY2009 trial in greenhouses (B) at DGRC; note the lack of disease symptoms in these resistant trees. Photos: Richard Sniezko (A), Emily Boes (B).

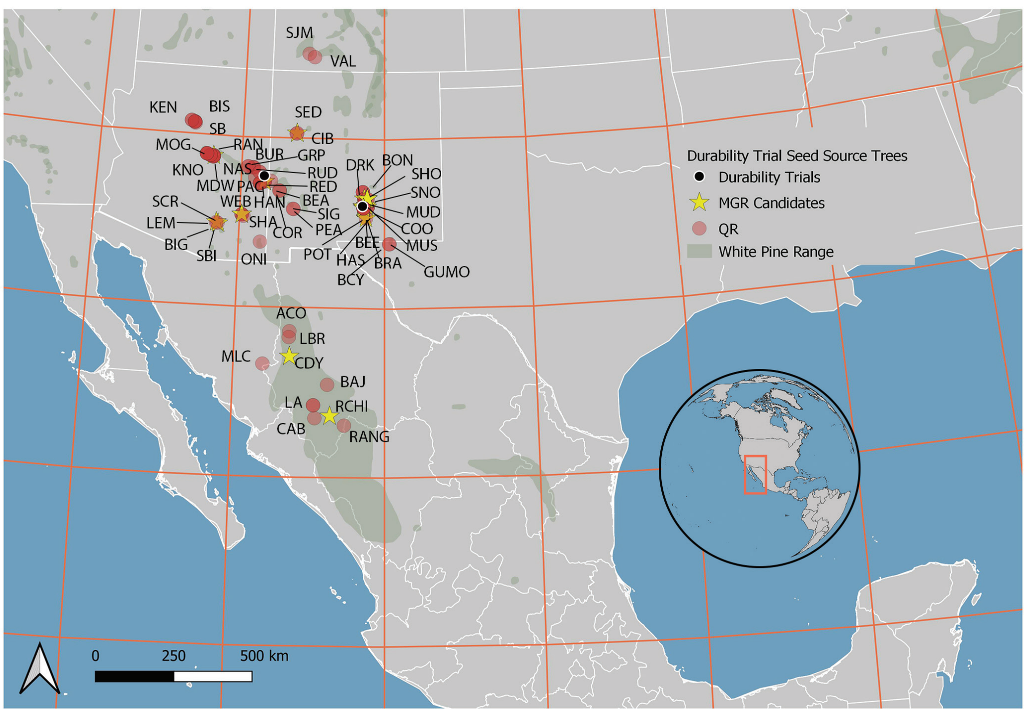

Figure 4. Locations of field sites and seed sources planted within the field sites.

the plantings thus far, we have experienced flooding, saturated soils, animal activity, and hot dry conditions, all of which have influenced survival. With challenges come great rewards, particularly the identification and conservation of the first documented WPBR-resistant genotypes of this species. This work is a collaboration between FHP, NAU, several national forests, and the Mescalero Apache Tribe (figure 7). This collaboration has provided great opportunities to work with, educate, and learn from all those involved in the project.

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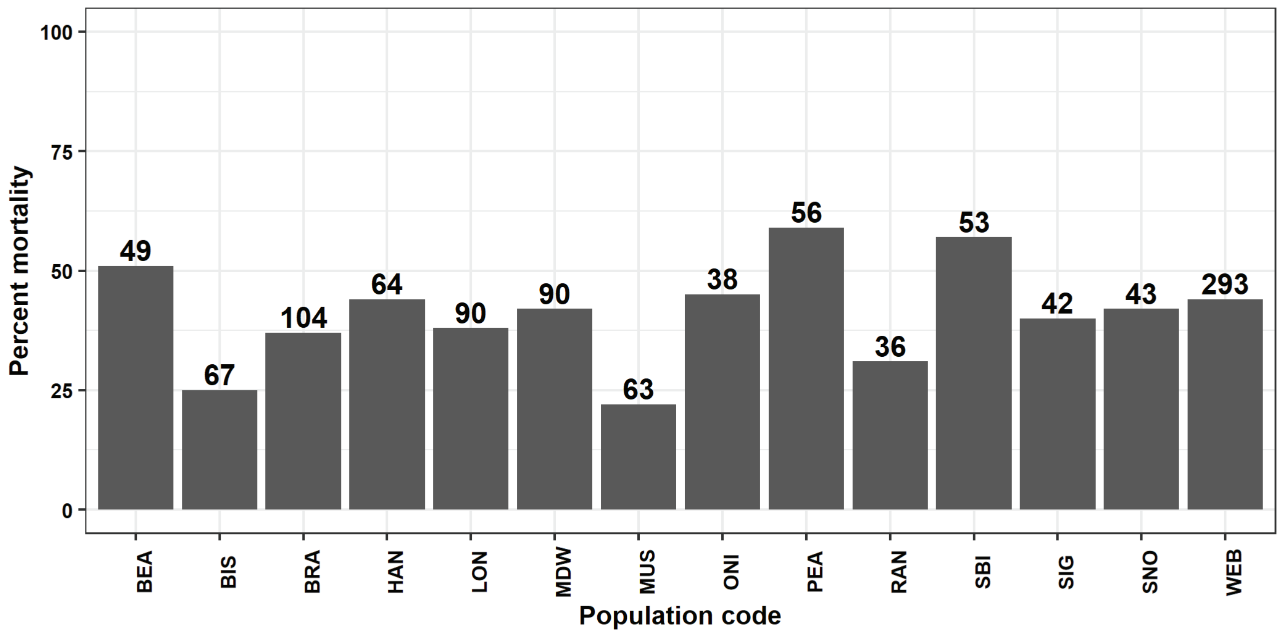

Figure 5. Percent mortality observed the year following planting by population at the Arizona field site. Number of individuals planted per population is displayed above bars. Only populations consisting of three or more individuals are presented.

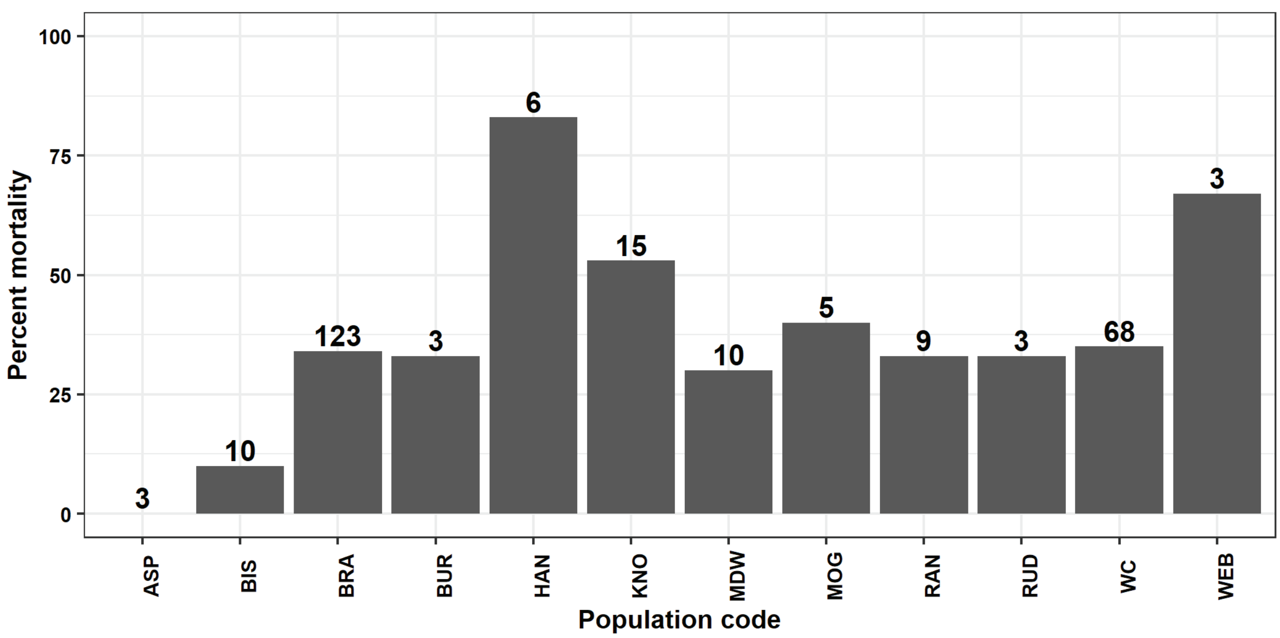

Figure 6. Percent mortality observed the year following planting by population at the New Mexico field site. Number of individuals planted per population is displayed above bars. Only populations consisting of three or more individuals are presented.

Figure 7. Planting of the field site located on Mescalero Apache Tribal Lands in 2021.

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