

## Establishing the Science Foundation to Sustain High-elevation Five-needle Pine Forests Threatened by Novel Interacting Stresses in Four Western National Parks

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**HIGH-ELEVATION FIVE-NEEDLE WHITE PINES** are among the most picturesque trees in many national parks, as well as other federal, state, and private lands in western North America. These trees often live to great ages; the trees' gnarled trunks give testimony to fierce winds that buffet them on exposed rocky sites. Ancient limber pines (*Pinus flexilis*) in Rocky Mountain National Park occupy the edge of Trail Ridge Road, and a remarkable old giant stands sentinel on the shore of Lake Haiyaha. Limber pines accompany Rocky Mountain bristlecone pines (*P. aristata*) on the exposed ridges around Mosca, Medano, and Music Passes in Great Sand Dunes National Park and Preserve, and Great Basin bristlecone pines (*P. longaeva*) top Wheeler Peak and Mount Washington in Great Basin National Park. Whitebark pines (*P. albicaulis*) grace the rim of Crater Lake and slopes of Mount Scott in Crater Lake National Park. Although the species may occur

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in only small areas within a park, they are ecologically invaluable to landscape dynamics and biodiversity, and vital for watershed protection (Tomback and Achuff 2010).

Whitebark and limber pine are declining across many parts of their range in the United States and Canada because of invasion by the non-native pathogen *Cronartium ribicola* that causes the lethal disease, white pine blister rust (WPBR), and outbreaks of native mountain pine beetles (*Dendroctonus ponderosae*), which are further exacerbated by fire exclusion and a changing climate (Keane and Schoettle 2011). These conditions have resulted in inadequate population size to sustain recovery processes in some whitebark pine ecosystems, and has led to whitebark pine's endangered species status (precluded) under the Endangered Species Act (USFWS 2011). Foxtail pine (*P. balfouriana*), southwestern white pine (*P. strobiformis*), Great Basin bristlecone pine, and Rocky Mountain bristlecone pine have not yet experienced the major declines observed in northern distributions of limber and whitebark pines, but they are in imminent danger from blister rust and beetles. Restoring declining populations and sustaining the remaining healthy populations present unique challenges for land managers.

In the mid-1900s, several parks, including Crater Lake and Rocky Mountain, participated in efforts to eradicate *Ribes* species, the alternate host to WPBR, in attempt to slow the pathogen's spread. The practice was later deemed ineffective and abandoned in the west, and the rust continues to invade forest ecosystems. A full spectrum of infection intensities and impacts to the white pines are displayed within the National Park Service (NPS). The northern parks, such as Glacier, Mount Rainier, and North Cascades, closest to the point of accidental introduction of the pathogen, have been infected for more than 60 years, and have the heaviest impacts. Only 5–10% of the whitebark pine trees in Glacier National Park remain alive today due to blister rust and bark beetles. More moderate impacts can be found in Crater Lake National Park, the Greater Yellowstone Ecosystem, and other mid-latitude parks and monuments. Further south, WPBR was confirmed in Great Sand Dunes National Park and Preserve in 2003 (Blodgett and Sullivan 2004), and in Rocky Mountain National Park in 2010 (Schoettle et al. 2011). Though impacts by WPBR are currently low in Rocky Mountain National Park, mountain pine beetle has caused high mortality among the pines, and recovery of the limber pine forests may be significantly impacted in the presence of WPBR. New infection centers are being found yearly in the Southern Rockies; it is clear that the pathogen is still spreading, and is now a permanent resident of our landscapes.

### **Building the science foundation to sustain and restore healthy ecosystems**

In this paper, we review the progress of Rocky Mountain, Great Basin, Great Sand Dunes, and Crater Lake national parks in building a science foundation to aid in the development of conservation strategies for high-elevation, five-needle pine ecosystems (Table 1). Due to the current impacts or threat of impacts, each of these parks considers their five-needle pine species of conservation concern. The science provides an assessment of the ecosystems, and reduces the uncertainty related to possible outcomes of interventions and consequences of inaction. Depending on the intensity of impact, efforts are focused on developing restoration activities in declining landscapes (restoration strategy), or proactive interventions in threatened ecosystems to mitigate future impacts (proactive strategy), or both (Keane and Schoettle 2011). Rocky Mountain, Great Basin and Great Sand Dunes national parks are currently following the proactive strategy approach, and Crater Lake National Park is taking the restoration strategy approach. The goal of both approaches is to conserve the species, and promote self-sustaining five-needle pine ecosystems in the presence of WPBR, using available tools and methods that are compatible with land use designations. Interagency collaboration between NPS and U.S. Forest Service has facilitated the progress of these conservation programs in each park.

National Park	Species	WPBR first confirmed	Current WPBR incidence	Active program initiated
Great Sand Dunes	Limber pine	2003	13%	2004
	RM bristlecone pine	2003	localized	
Rocky Mountain (RM)	Limber pine	2010	0% (eradicated?)	2008
Great Basin (GB)	GB bristlecone pine	--	0%	2011
	Limber pine	--	0%	
Crater Lake	Whitebark pine	1941	25% widespread	2003

**Table 1.** Status of white pine blister rust in the four western National Parks discussed in this paper.

Sustaining population resilience requires maintenance of recovery capacity after disturbance, and genetic diversity to support adaptive capacity over time. Therefore, conservation approaches must incorporate a long-term and evolutionary perspective, which also incorporates adaptation to climate change (Schoettle et al. 2012). Tree longevity is not enough for multigenerational sustainability; sustainability depends on an intact regeneration cycle and, in the presence of WPBR, increased disease resistance to support recovery capacity. These conservation programs include in situ and ex situ genetic conservation, evaluating parent trees for genetic resistance to WPBR, pine regeneration dynamics, planting trials, and monitoring forest health stressors.

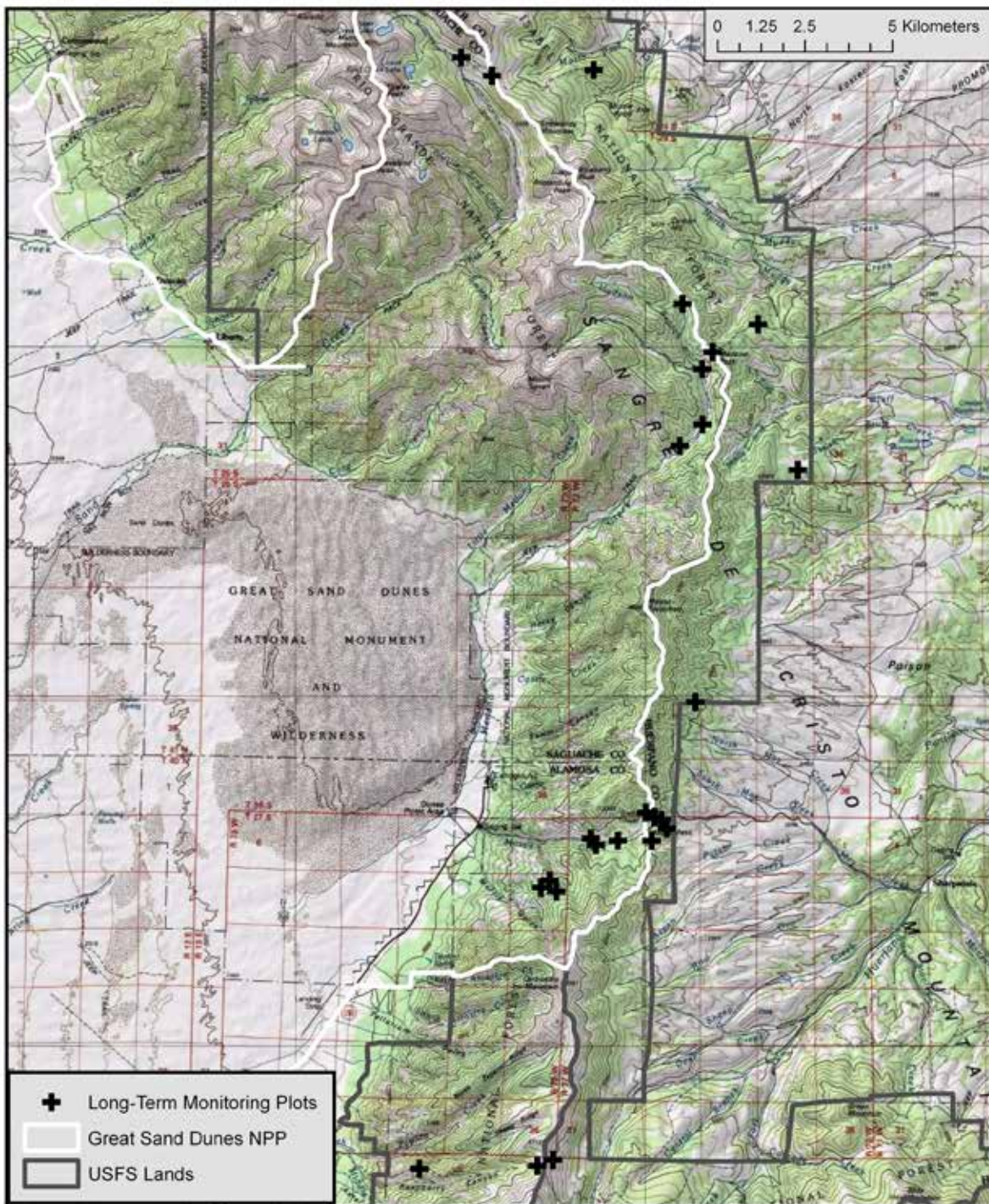
### Sampling framework

Each of the four parks discussed here has established a different sampling design for their high-elevation pine programs. Crater Lake National Park started its WPBR incidence assessments in 2000 and 2002 (Murray and Rasmussen 2003), with tree assessments within 24 transects, and more recent plots have been installed in additional areas (Smith et al. 2011). At Great Sand Dunes National Park and Preserve, forest health assessment plots were installed in 2004, radiating out from the initial WPBR infection center (Figure 1; Burns 2006). In 2008, Rocky Mountain National Park and the U.S. Forest Service established 17 limber pine sites in the park, and 10 sites outside the park, to serve as the sampling framework for the limber pine conservation project (Figure 2; Schoettle et al. 2011). This cross-boundary network of sites (populations) was stratified by elevation to capture the full breadth of limber pine habitats in the greater geographic area. Great Basin National Park established three areas of concentration in 2011, and additional plot networks, assessments, and samplings are under development.

### Ex situ genetic conservation

Across these four parks, extensive seed collections are now archived, and comprise some of the first gene conservation collections for the parks (Table 2). These collections provide insurance against impacts of climate change, seed material for testing progeny of parent trees for resistance to WPBR, and baseline materials for genetic studies to detect changes in diversity. Initial whitebark pine seed collections in Crater Lake National Park targeted healthy trees within heavily WPBR-impacted stands for resistance testing, an approach utilized in tree improvement programs, and

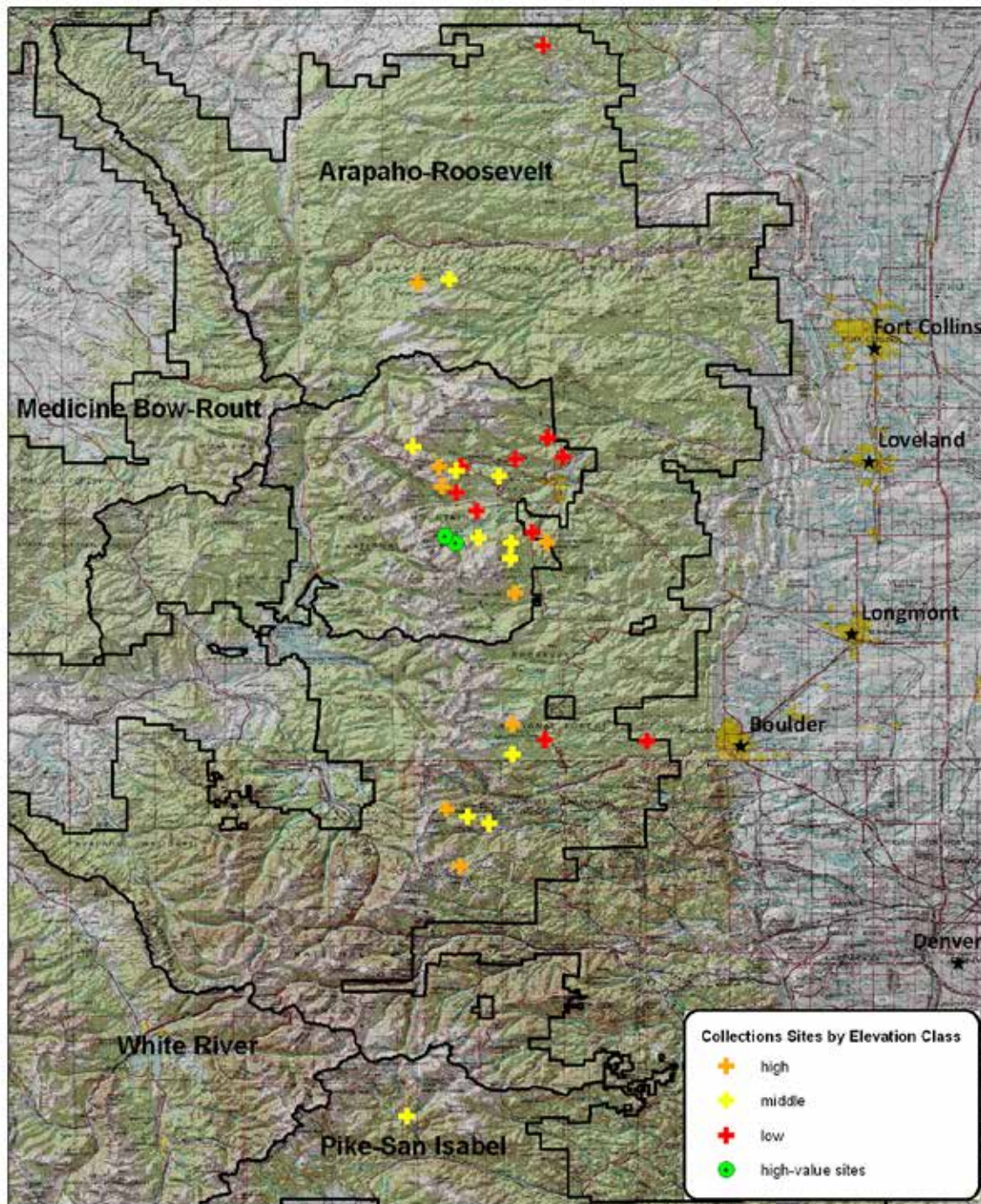
## Long-Term Monitoring Plots in the Sangre de Cristo Range



**Figure 1.** Location of forest health and regeneration assessment plots in Great Sand Dunes National Park and Preserve (adapted from Burns 2006). The plots were first installed in 2004 and are currently being remeasured. Plots include Rocky Mountain bristlecone and limber pine trees; seed collections of both species have been made in the Mosca Pass area.



## Sampling Sites in the Greater Rocky Mountain National Park Area



**Figure 2.** Network of limber pine sites (17 sites and 2 high values tree sites) and around (10 sites) Rocky Mountain National Park that serve as the sampling framework for the limber pine conservation program (adapted from Schoettle, Klutsch, and Sniezko 2011). The sites were selected to represent the diversity of limber pine habitats in the park. The sites are stratified by elevation; the mean elevation for low, moderate and high elevation sites of 2740 m, 3080 m, and 3320 m, respectively (full elevation range of the sites is 2450 m to 3430 m). Seed collections, forest health and regeneration assessments, and verbenone deployment have been focused in these limber pine populations.

National Park	Species	Individual-tree seed collections	Seed lots in testing	Resistance found?
Great Sand Dunes	Limber pine	39	23	Yes (6/23)
	RM bristlecone pine	13	(0 from park)	(Yes)
Rocky Mountain	Limber pine	213 + 44 bulk	124 + 16 bulk	Yes (18/87)
Great Basin (GB)	GB bristlecone pine	9 + 1 bulk	9 + 1 bulk	In process
	Limber pine	Planned	Planned	Planned
Crater Lake	Whitebark pine	101	70	Yes (16/35)

**Table 2.** The number of individual-tree and bulked seed lots from five-needle pine species in each of the four parks currently in WPBR resistance testing at the USFS Dorena Genetic Resource Center (Cottage Grove, OR) and, for those tests that are completed, the number of individual-tree seed lots that demonstrated signs of WPBR resistance is reported in parentheses (# with resistance/# tested). The seed collections are also archived for ex situ conservation. Rocky Mountain (RM) bristlecone pine from other locations in Colorado have shown evidence for genetic resistance to WPBR, yet no lots from within Great Sand Dunes National Park and Preserve have been tested yet. This table does not differentiate among the types of resistance found yet it is accepted that populations with greater diversity of resistance mechanisms will likewise be the most resilient. In most cases, additional testing is needed to comprehensively quantify the diversity of WPBR resistance types present in each species and park.

more recently collection has expanded throughout the park's whitebark pine distribution (Figure 3). Similarly, Rocky Mountain bristlecone and limber pine individual-tree seed collections in Great Sand Dunes National Park and Preserve are concentrated near the WPBR infection areas and not directly associated with the plot networks. A sampling approach more typical for conservation programs has been adopted by Rocky Mountain and Great Basin National Parks where WPBR is thought to be currently absent. Individual-tree seed collections, and a bulked seed collection have been attempted from each of the 27 limber pine populations in and around Rocky Mountain National Park (Figure 2). Seed collections of Great Basin bristlecone pine began in 2011 in Great Basin National Park and more extensive collections are planned park-wide for both Great Basin bristlecone and limber pine.

#### ***In situ* protection and conservation**

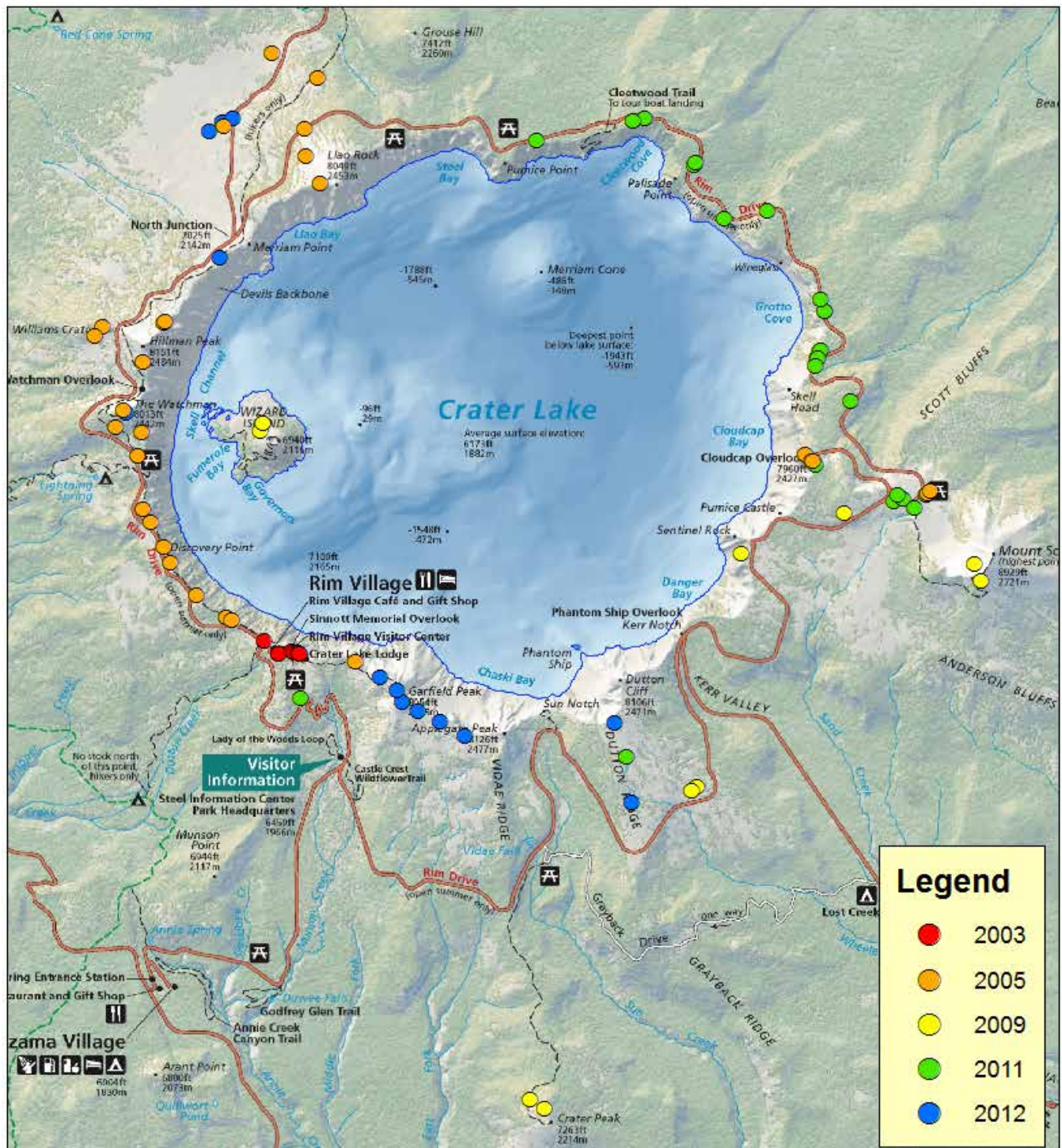
Active protection of seed trees from mountain pine beetle and fire, when feasible, is ongoing. The seeds from these trees are used to test for genetic resistance to WPBR (see below); when resistance is found, additional seed is collected to build seed stocks for planting or seeding. These trees are an important component of the long-term conservation strategy. In Crater Lake National Park in recent years, mountain pine beetle has surpassed WPBR as the primary mortality agent of whitebark pine, and has killed several seed trees with genetic resistance to WPBR; mountain pine beetle has likewise caused extensive mortality of limber pine in Rocky Mountain National Park. In these parks, and Great Basin National Park, an anti-aggregate pheromone (verbenone) is used to repel mountain pine beetle, and provide *in situ* protection of the trees from which seed collections have been made. Additional mature limber pine trees are also protected from mountain pine beetle in Rocky Mountain National Park to help support natural regeneration, and a third group of limber pine trees is protected because they are highly valued by park visitors. The seed trees



# Crater Lake National Park

## Whitebark Pine Cone Collections, 2003-2012

National Park Service  
U.S. Department of the Interior



**Figure 3.** Whitebark pine seed tree locations in Crater Lake National Park by seed collection year.

are also listed as resources at risk for potential protection from wildfire; though some limber pine seed trees may have been recently lost in the 2012 Fern Lake Fire in Rocky Mountain National Park. Mountain pine beetle activity is low in Great Sand Dunes National Park and Preserve, so in situ protection of the seed trees has not yet been necessary.

#### **WPBR resistance trials**

Reducing the effect of disease on tree survival and fecundity, by increasing heritable disease resistance, is essential to sustaining many pine populations. WPBR resistance testing is a progeny test, requiring artificial inoculation of pine seedlings with *C. ribicola* in a nursery setting, followed by disease assessments. The testing process can take two to seven years, depending on the resistance mechanism being investigated. Several testing centers administered by the U.S. Forest Service operate in the western United States (Snieszko et al. 2011); the testing of the plant material from these parks is being conducted at Dorena Genetic Resource Center (Cottage Grove, OR). Past studies revealed disease resistance in each North American five-needle pine species, and current studies demonstrate an encouraging frequency of genetic resistance within national parks (Table 2).

Because the seed sources from Rocky Mountain National Park and Great Basin National Park were sampled without bias toward disease-free trees in the field (in areas with no WPBR present), these resistance trials provide estimates of the baseline frequencies of resistance in the native pine populations. Disease-resistance frequency and its geographic distribution provides valuable information for designing, prioritizing, and evaluating management options. Healthy populations in which resistance is present at moderate frequency can be seed sources for outplanting in similar habitats with less resistance, and can be managed to facilitate rust-resistance selection, and therefore accelerate the evolution of resistance throughout the population once WPBR invades (Schoettle and Snieszko 2007). A common garden study for limber pine was also conducted for Rocky Mountain National Park seed sources to identify genetic differentiation among populations and guide seed transfer decisions should outplanting or assisted migration be recommended.

#### **Planting trials and natural regeneration dynamics**

In populations with few or no WPBR-resistant parent trees, planting or direct-seeding resistant stock will be needed to sustain the community. In addition, planting may be recommended to increase the population size, if natural regeneration is sparse. Planting studies help define the techniques for high seedling survival, and can verify field expression of rust resistance identified in the WPBR resistance trials. Crater Lake National Park has installed four whitebark pine restoration plantings since 2009 (totaling 939 seedlings). Three years after planting, survival has been over 80%, and as high as 91%. Limber pine plantings at Great Sand Dunes National Park and Preserve have demonstrated over 70% survival, four years after planting (A.M. Casper et al., in preparation). These and other trials suggest that planting can be successful and feasible in these high-elevation habitats. Thus far, planting in Crater Lake and Great Sand Dunes National Parks has been outside of designated or proposed wilderness. Planting may be acceptable within wilderness, as it has been practiced with whitebark pine in Glacier National Park for the past 10 years. Rocky Mountain National Park is 95% wilderness, and a strategic plan that is being developed will help define appropriate actions for inside and outside wilderness.

For the high-elevation, five-needle pines, generation time is very long, and seedling establishment after disturbance is protracted. These species are tolerant of the stresses they evolved with, but are not well equipped, without additional regeneration opportunities, for rapid adaptation to novel stresses, such as WPBR in a changing climate (Field et al. 2012). A study conducted three decades after the stand-replacing Ouzel Fire of 1978 revealed high regeneration



capacity of limber pine in Rocky Mountain National Park (Coop and Schoettle 2009); geographic variation in regeneration among the limber pine study sites in and around Rocky Mountain National Park will add further information (J. Klutsch et al., in preparation). At Great Sand Dunes National Park and Preserve, seedling densities of limber pine and Rocky Mountain bristlecone pine are being assessed through repeat measurement of the established plot network (Figure 2).

### Integration and application

Studies described here, and others, provide a science foundation from which conservation plans are currently being drafted for Crater Lake National Park (Beck and Holm 2013) and Rocky Mountain National Park. The studies also provide knowledge pertinent to the greater geographic areas, and contribute to broader scientific understanding of these pine species, and to WPBR, and disturbance dynamics in these mountain ecosystems. Data from these studies are also being used to prioritize areas and treatments and align expectations for outcomes. This knowledge reduces the uncertainty in projecting outcomes of interventions or inactivity to improve trade-off analyses as managers assess their options; it can also feed into economic analyses as well (Bond et al. 2011). These programs may also provide conservation areas or refugia for the pines. Restoration treatments can slow impacts and rebuild impacted populations, and proactive interventions can help prepare the landscape for invasion to mitigate the severity of future impacts. Building a timely, solid science foundation assists in the careful consideration of the consistency of interventions, and consequences of no interventions, with park and wilderness policies and values as the ecosystems are challenged by non-native diseases or other factors. Through productive interagency collaborations and partnerships, each of these parks is using science to responsibly and creatively conserve and manage their resource for increased resilience to these novel, interacting stresses.

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