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Not on Our Watch: Scientists and Managers Rush to Save High-Elevation, Five-Needle Pines

High-elevation, five-needle white pine species, known by many researchers and managers as the high-five pines, are some of the most unique and iconic tree species in North America. Living for centuries and inhabiting the harshest sites possible—cold, wind-swept mountain peaks and exposed mountain ridges—these species epitomize endurance, survival, and adaptability.

Yet, many of the high-five forests in western North America face a murderers' row of threats, including

FWS Lists Whitebark Pine as Threatened Species

On December 15, 2022, the U.S. Fish and Wildlife Service (FWS) listed whitebark pine as threatened with potential extinction under the Endangered Species Act. FWS determined that the primary stressor driving the status of whitebark pine is white pine blister rust, a fungal disease caused by the nonnative pathogen *Cronartium ribicola*. Whitebark pine (*Pinus albicaulis)* is also negatively affected by the mountain pine beetle (*Dendroctonus ponderosae*), altered fire regimes, and the effects of climate change.

The threatened designation is a long-time in the making. Whitebark pine has been a candidate for listing since 2011, with petitions for federal protection for the species stretching back to 1991. Whitebark pine is already listed as endangered in Canada under the Species at Risk Act.

"The listing provides an outstanding opportunity to expand collaboration across agencies to restore the species—for example, with the National Whitebark Pine Restoration Plan," says Diana Tomback, a forest ecologist and conservation biologist with the University of Colorado Denver. "We have the tools and capability to make populations more resilient to the threats. The hard work now begins to ensure that whitebark pine has a future."

Great Basin bristlecone pine, USDA Forest Service photo by A.W. Schoettle an invasion by the non-native fungal pathogen *Cronartium ribicola* that causes white pine blister rust (WPBR) and outbreaks of the native mountain pine beetle (MPB) (*Dendroctonus ponderosae*), which have increased with rising temperatures and drought related to climate change.

The high-five species include whitebark (*Pinus albicaulis*), limber (*P. flexilis*), southwestern white (*P. strobiformis*), foxtail (*P. balfouriana*), Rocky Mountain bristlecone (*P. aristata*), and Great Basin bristlecone (*P. longaeva*) pines. These pines play important functional roles in high-elevation ecosystems, with some acting as keystone and foundation species, providing stability to watersheds and supporting biodiversity. Many of these pines produce large, high-calorie seeds (containing approximately 50% fat) that are an important food source for diverse wildlife species, including small mammals, grizzly bears, and birds such as Clark's nutcrackers. High-five trees contribute to snow capture and retention at high elevations, preventing soil erosion and improving water quality.

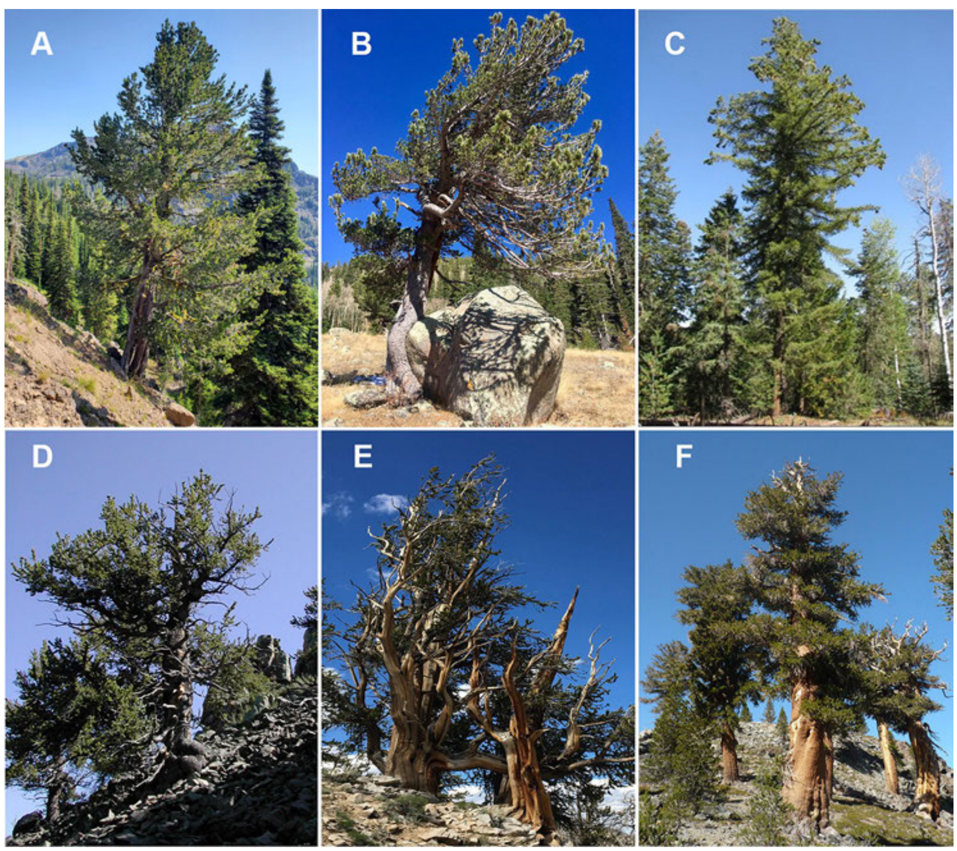
Summary

The high-elevation, five-needle (high-five) pines play important functional roles in high-mountain ecosystems, with several acting as keystone and foundation species, providing stability to watersheds and supporting biodiversity.

The high-five pines include the montane, subalpine, and treeline species—whitebark (*Pinus albicaulis*), limber (*P. flexilis*), Rocky Mountain bristlecone (*P. aristata*), Great Basin bristlecone (*P. longaeva*), foxtail (*P. balfouriana*), and southwestern white (*P. strobiformis*) pines.

Many high-five pines are threatened by a confluence of disturbances and stressors, including white pine blister rust caused by the nonnative pathogen *Cronartium ribicola*, outbreaks of mountain pine beetle (*Dendroctonus ponderosae*), wildfire impacts, and water and temperature stress associated with climate change. Whitebark and limber pine forests are rapidly declining because of impacts from white pine blister rust and mountain pine beetle. The other high-five pines—Great Basin bristlecone, Rocky Mountain bristlecone, foxtail, and southwestern white pine—have yet to experience the widespread declines observed in limber and whitebark, but all are also in imminent danger.

At a seminal high-five conference in October 2021, scientists, managers, and resource professionals discussed the plight of high-five forests and management solutions. A special issue of the journal Forest Ecology and Management hosted keynote and plenary papers presented at the conference documenting the decline of high-five ecosystems, describing the ecology and current forest conditions, and presenting various tactics and strategies that can be implemented to conserve and restore the high-five pines to the landscape.



High-Five Species

A) whitebark pine, photo by D.F. Tomback;

B) limber pine, photo by C.T. Holtz;

C) southwestern white pine, photo by K.M. Waring;

D) Rocky Mountain bristlecone pine, USDA Forest Service photo by A.W. Schoettle;

E) Great Basin bristlecone pine, USDA Forest Service photo by A.W. Schoettle;

F) foxtail pine, photo by S.T. McKinney.

Whitebark and limber pine are already declining across their ranges in the United States and Canada. WPBR and MPB have transformed healthy stands of whitebark pine into vast ghost forests of standing dead trees in a matter of decades. The state of whitebark pine is so grim that the U.S. Fish and Wildlife Service has listed whitebark pine as a threatened species under the Endangered Species Act, an unusual step for a tree species (see Sidebar, page 1).

"Some of these populations that are on the edge evolved over a long time and have a huge genetic pool of traits to handle these kinds of changing conditions," says Barbara Bentz, Rocky Mountain Research Station (RMRS) research entomologist. "We want to keep those traits in the genetic pool. But we could lose them if this level of mortality continues."

Foxtail pine, southwestern white pine, Great Basin bristlecone pine, and Rocky Mountain bristlecone pine haven't yet experienced the major declines observed in limber and whitebark pines, but they are

High-Elevation, Five-Needle Pine Species: *Overview and Outlook*

Whitebark pine, an upper subalpine and treeline species, ranges from southwest Canada south to the California Sierra Nevada and Great Basin; and the Canadian Rocky Mountains south through Wyoming. It often occurs abundantly as the only tree species on some of the coldest and driest sites in krummholz treeline communities. The outlook for whitebark pine is somewhat discouraging because mortality has been very high and resistance to WPBR is highly variable among populations. Researchers believe the species can adapt and recover but requires forest management and restoration to increase frequencies of WPBR-resistance in populations to ensure long-term population viability.

Limber pine has a broad western distribution and elevation range, from British Columbia and Alberta in Canada south to New Mexico and the Sierra Nevada in California. Limber pine sites tend to be warmer in the summer and have lower precipitation year-round than those supporting whitebark pine. Limber pine is highly susceptible to WPBR and bark beetles and, like whitebark pine, requires forest restoration where mortality is high. In areas where WPBR infection is low or not present, limber pine may adapt more readily to the effects of climate change than other high-five species, and proactive management can help accelerate the increase of WPBR resistance to sustain healthy limber pine populations into the future.

Southwestern white pine occurs at mid to high elevations in mixed-conifer forests upslope from ponderosa pine (*Pinus ponderosa*) in Arizona, New Mexico, and northern Mexico. Southwestern white pine has moderate levels of genetic resistance to WPBR and has drought-tolerant traits but is susceptible to MPB and dwarf mistletoe. Wildfires can also threaten entire populations on isolated "sky islands." Southwestern white pine has high adaptive potential, and management strategies can address climate adaptation and other stressors in the mixed-conifer forest type.

Rocky Mountain bristlecone pine's distribution is in central Colorado, and into New Mexico and northern Arizona. Rocky Mountain bristlecone pine grows from 8,200 to 12,000 feet in elevation in large and small stands, as well as isolated trees on rocky outcrops. It often forms spreading krummholz mats above the treeline. Rocky Mountain bristlecone forests are tolerant to drought and currently have low levels of WPBR infection and moderate levels of resistance to WPBR. Rocky Mountain bristlecone's key vulnerability is its very low genetic diversity, which may hinder adaptation to these stressors in the future. Management actions that increase the abundance of younger cohorts with more diverse genetic combinations could improve its adaptive capacity and outlook.

Great Basin bristlecone pine, the longest-lived non-clonal organism globally, grows on isolated mountain ranges and sky islands in western Utah, Nevada, and eastern California at elevations between 6,400 and 11,600 feet. WPBR is not yet present within its range, but Great Basin bristlecone pine is susceptible to rust infection under lab conditions (a partnership between RMRS and the National Park Service is underway to proactively identify genetic resistance to WPBR in this species). Great Basin bristlecone pine is not a suitable host for bark beetles (unless severely stressed and growing with other pines that are hosts to bark beetles, as explained elsewhere in this bulletin). Its ability to recover from disturbances is limited by its low and sporadic levels of seedling establishment, which may become even less common under climate change. Coordinated monitoring for new mortality throughout the range of Great Basin bristlecone pine can identify populations that may require protection.

Foxtail pine has a restricted distribution, with one portion in the Klamath Range in northern California and the other in the southern Sierra Nevada Mountains. Foxtail pine forests are in good condition, primarily because WPBR is only present in the northern population and nearly absent in the southern foxtail stands. However, foxtail pine is vulnerable to the continued spread of the disease and could be further protected with interventions to increase the frequency of genetic resistance to WPBR. Foxtail pine has intermediate resistance to bark beetles, and monitoring with appropriate treatments will be required.

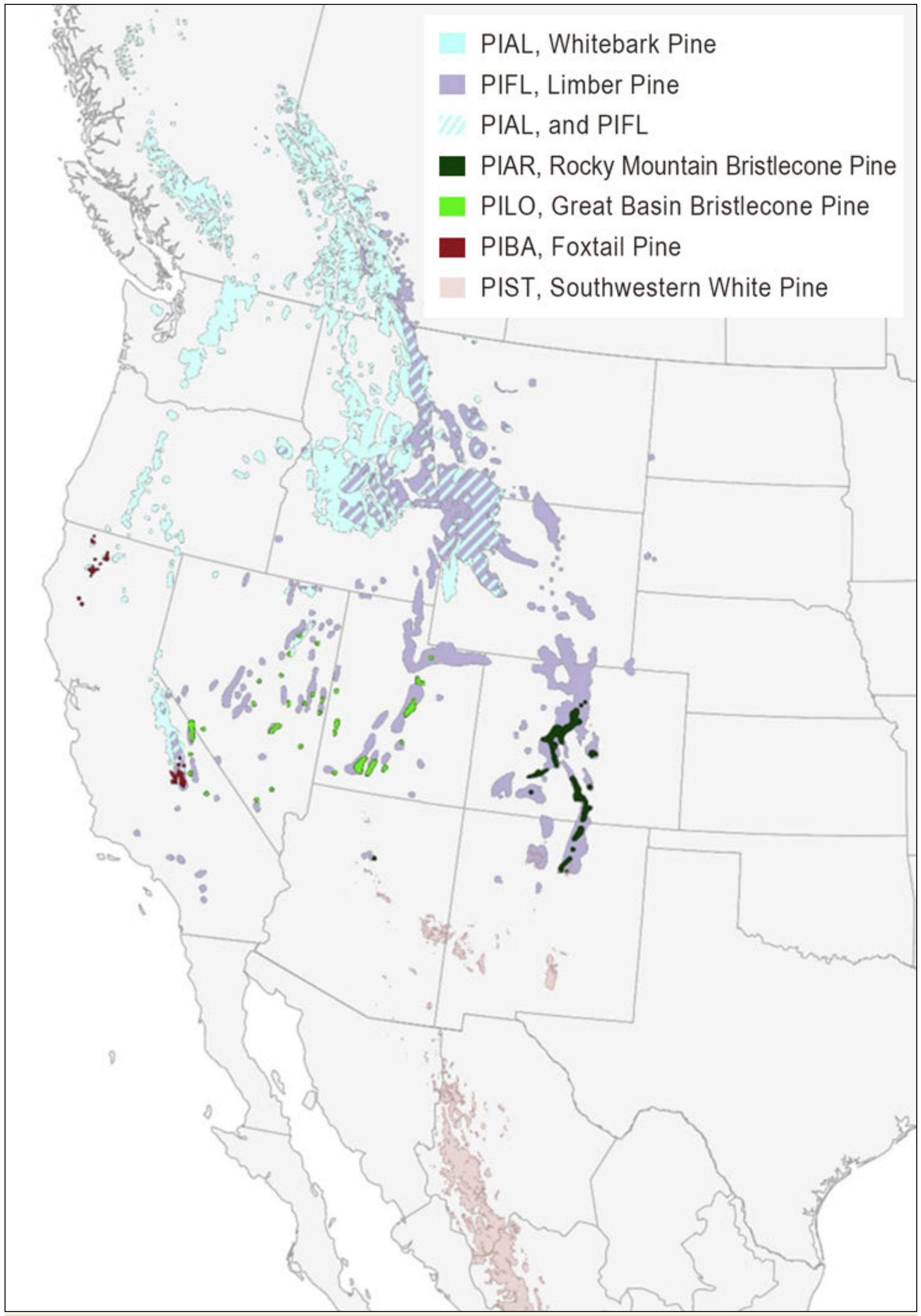
also in danger from WPBR, MPB, wildfire, and impacts from climate change.

Despite the bleak future for these species, researchers remain optimistic about our capacity to conserve and restore these unique forests. Over the past few decades, scientists have honed a set of strategies and techniques at multiple scales to build genetic resistance to blister rust and resilience to disturbance. In October 2021, the Whitebark Pine Ecosystem Foundation held a conference that brought together the high-five research and management community to discuss potential solutions to the threats facing high-five pine forests. The journal Forest Ecology and Management published a special issue dedicated to papers presented by keynote and plenary speakers at the conference. Here, we highlight some key findings from those papers and describe the efforts to promote self-sustaining high-elevation, five-needle pine forests.

The Big Picture

Sara Goeking, an RMRS supervisory biologist, draws on her five years as a Forest Inventory and Analysis (FIA) crew leader to examine trends in forest dynamics, particularly mortality and disturbance, and land use/land cover change using FIA data. The FIA program samples from a network of permanent monitoring plots across the country each year as a survey of the nation's forests, providing invaluable and continuous information on forest health, tree growth and mortality, wildlife habitat, and land use change, among many attributes.

Goeking used FIA datasets to conduct broad-scale demographic assessments for the high-five pine species. She looked at changes in abundance (number of individuals), tree density, size-class distribution, recruitment, growth



Distribution of the high-five species in western North America. From Schoettle et al. 2022 rates, mortality, and causes of mortality from 2010 to 2019 across the western United States.

The analysis showed a marked decline in both whitebark pine and limber pine due to increased mortality from WPBR and MPB and decreased rates of growth and regeneration. Whitebark has been hard hit, as evidenced by the percentage of standing dead whitebark pines recorded in the FIA survey. In 2019, about 54% of all standing whitebark pine trees were dead, an increase from 43% in 2009 and only 12% in 1999.

A WPBR-infected whitebark pine krummholz at treeline in the northern Rockies. Photos by D.F. Tomback

Limber pine mortality caused by mountain pine beetle, Humbolt-Toiyabe National Forest, NV. USDA photo by B. Bentz

Goeking says that limber pine previously had a lower mortality rate than whitebark pine, but the analysis showed signs of limber decline that were like that of whitebark 10 years earlier. Limber pine tends to grow in drier habitats than whitebark pine, which can lead to lower chances of WPBR infection. However, limber pine appears to be following a similar, albeit delayed, trajectory of decline.

Characteristic white pine blister rust canker erupting on a Rocky Mountain bristlecone pine trunk. USDA photo by A.W. Schoettle

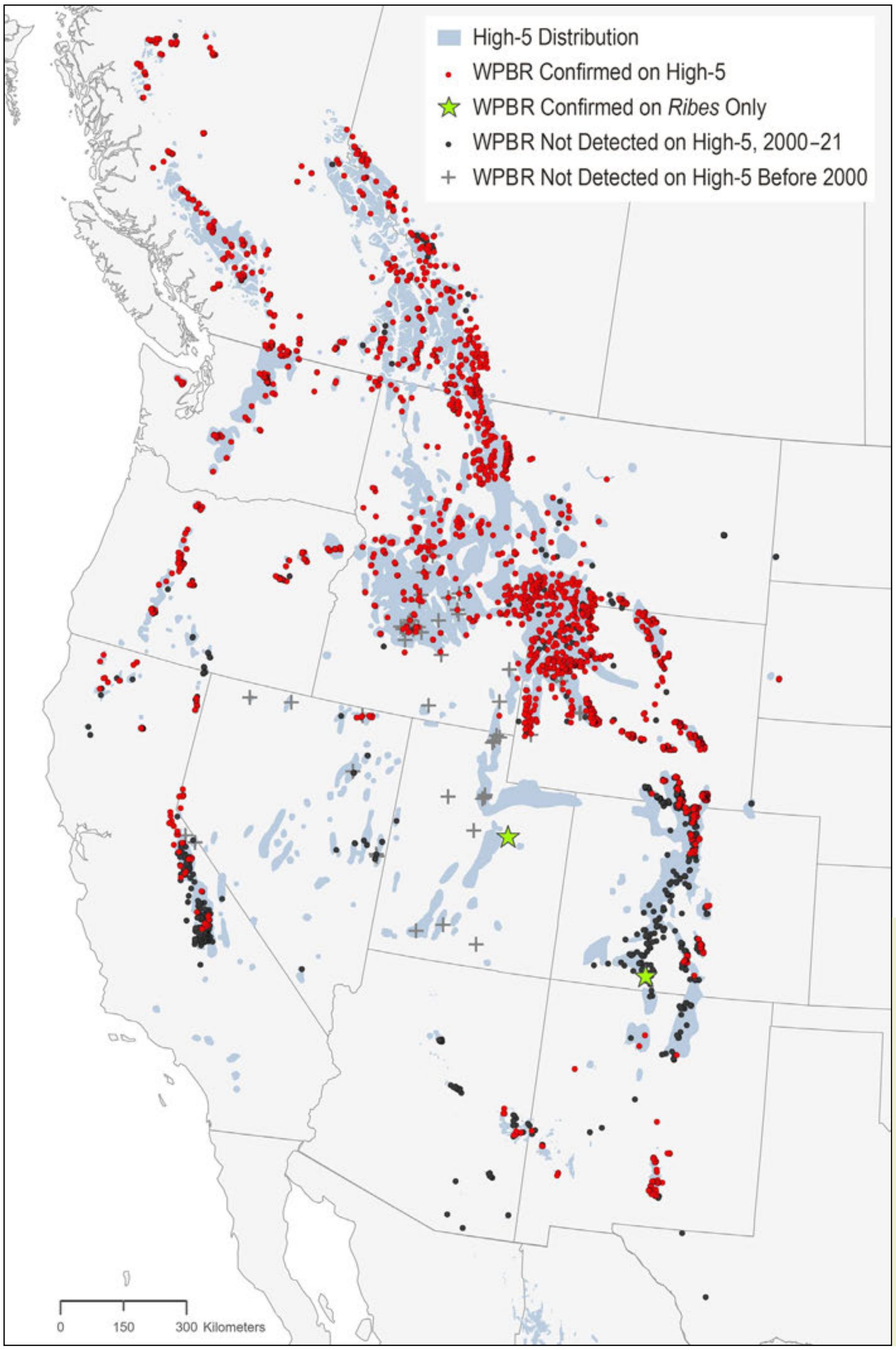
One of the more surprising results of Goeking's analysis was that most of the recruitment for whitebark and limber pine was in other forest types, lodgepole and Douglas-fir, at lower elevations.

"Many people think that whitebark and limber have a very narrow niche because they are obvious at the tops of the mountains," says Goeking. "But they're found all the way down. I've hiked up to whitebark pine stands that were

4,000 to 5,000 feet higher than where I started, but I've seen whitebark seedlings the entire way."

She suggests managers also consider treatments to reduce threats from wildfire, insects, and diseases to the lower-elevation whitebark and limber pine because these stands might contain trees with genetic resistance to WPBR.

Goeking's study also found that southwestern white pine had declined, but analysis showed this wasn't due to WPBR and bark beetles but a series of large wildfires in the Southwest that had significant impacts on the species.



Distribution of white pine blister rust (WPBR) on the high-five species in western North America, as of 2021. Red dots indicate locations where C. ribicola has been detected on high-five species, black dots where C. ribicola has not been detected on high-five species (since 2000), and green stars are where C. ribicola has been confirmed on the alternate host Ribes inerme but has not been detected on nearby five-needle pines hosts. Grey crosses indicate areas where rust was not detected before 2000 and more recent data is unavailable. The distribution of the high-fives is displayed in grey. From Schoettle et al. 2022

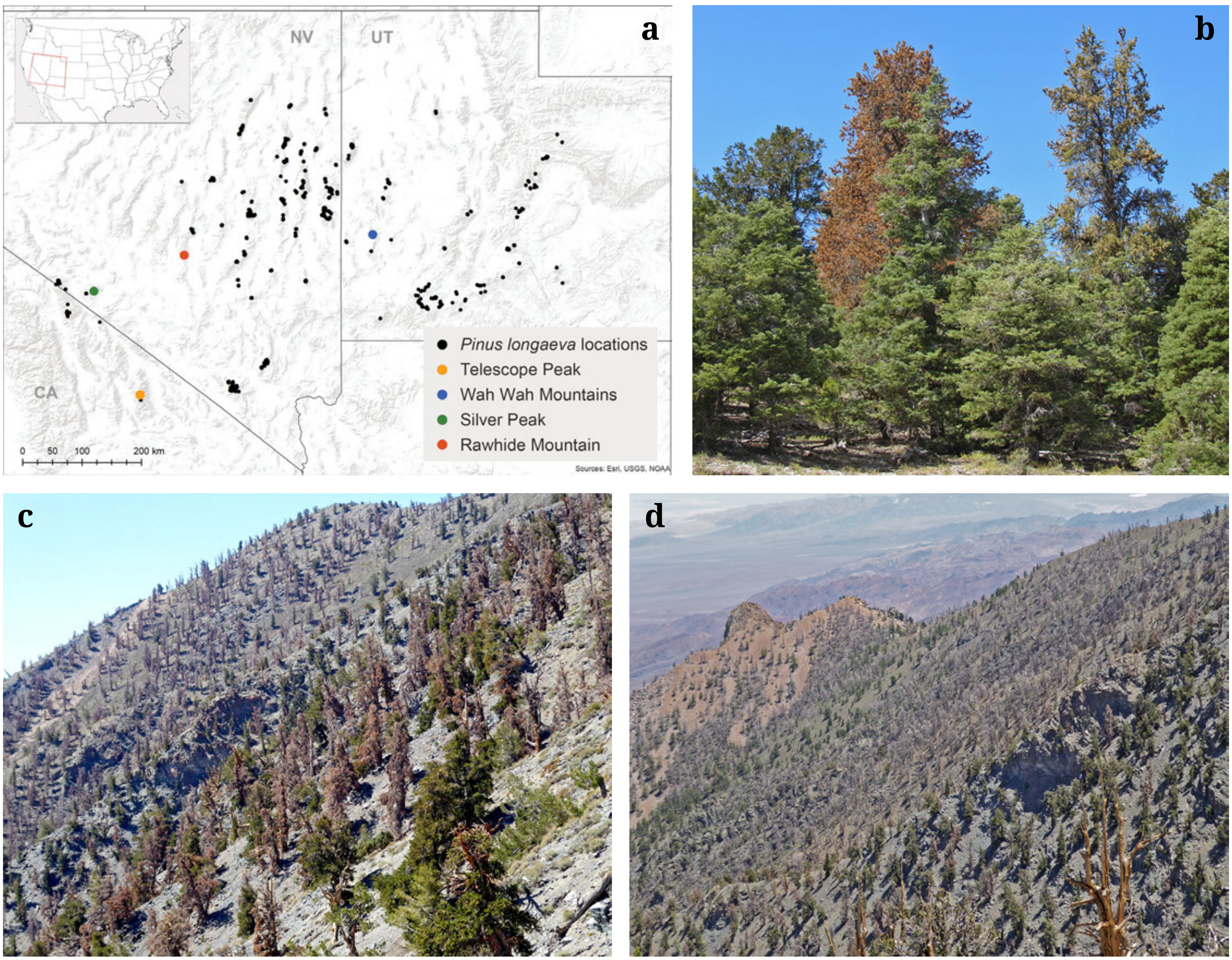
Building Adaptive Capacity to WPBR and Climate Change

WPBR first arrived in western North America in the early 1900s through live pine seedlings imported from Europe. The fungal pathogen produces cankers with orange spore sacs on the branches and trunks of infected trees that girdle the stem and kill the tree. All the high-five pines are susceptible to *C. ribicola* at varying levels, but whitebark pine mortality is as high as 90 percent, leaving behind "ghost forests" of dead trees.

"Some species are in better shape than others because they are experiencing less pressure from white pine blister rust, although the rust continues to spread. It's not uniform, and each species has its own vulnerabilities, its own Achilles heel," says Anna Schoettle, an RMRS research plant ecophysiologist who has been working on high-five responses to environmental conditions and blister rust since 1998.

In an analysis of the adaptive capacity of each high-five species, Schoettle and co-authors highlight that natural selection occurs at the population level, so the challenge under intense selection by WPBR is to maintain a viable population size with enough genetic diversity to support a self-sustaining population. Schoettle says that for the high-five species, this means that the continuous process of adaptation is a consequence of WPBR-caused mortality of trees with less genetic resistance (they are selected against) and the survival of those with genetic resistance to WPBR. As these resistant trees reproduce, the frequency of trees with genetic resistance traits increases, eventually leading to recovery. If the rate of mortality is too rapid, from WPBR and other stressors, the population size can drop below a threshold from which it cannot recover.

For most of the high-five species, slow maturation to reproductive age makes adaptation and recovery more



Great Basin bristlecone pine mortality. a) Geographic locations of field-verified Great Basin bristlecone pine habitats, highlighting locations with recently observed Great Basin bristlecone pine mortality; b) Great Basin bristlecone pine mortality at the Wah Wah Mountains site, USDA photo by B. Bentz; c, d) limber pine and Great Basin bristlecone pine mortality at the Telescope Peak site, photos by C. Millar complicated. It takes at least 30-50 years from seedling establishment until these pines produce their first cone crop and decades more before they mature to produce a sizable cone crop. For each of the high-five pines, bark beetles, wildfire, and drought heighten the risk of severe population decline and reduce the likelihood of adaptation to WPBR and climate change. For managers working to conserve these species and accelerate adaptation to the stressors, preserving genetic diversity is crucial.

"We have to find genetically resistant trees and increase their numbers on the landscape using the silvicultural and forest management practices that we already have," says Schoettle. "Finding those individuals or populations that have higher resistance isn't something new. So, it's not like we're waiting for a miracle: we just have to get to work."

A Surprise in Death Valley

Researchers have long thought Great Basin bristlecone pines were safe from the threats affecting other high-five species. So far, researchers have found no signs of WPBR in the Great Basin bristlecone range (though the species is susceptible to the disease), and the traits that allow the species to thrive in the harshest and driest high-elevation sites should give it a leg up in adapting to the effects of climate change. And until recently, researchers also thought Great Basin bristlecone pines were resistant to bark beetles.

So, it surprised RMRS research entomologist Barbara Bentz when she peeled back the bark of a dead Great Basin bristlecone pine on Telescope Peak in Death Valley National Park and found MPB galleries. Bentz was conducting a survey of bristlecone mortality with her colleague Constance Millar, a research ecologist and scientist emerita with the Forest Service's Pacific Southwest Research Station. They also found another bark beetle, pinyon ips (*Ips confusus*), attacking Great Basin bristlecone pine in other parts of the range. Both bark beetle species have not previously been recorded in Great Basin bristlecone pine.

She says temperatures are increasing faster at higher elevations with climate change, and the warmer conditions have led to increased bark beetle activity at higher elevations, especially in limber pine, which often co-occurs with Great Basin bristlecone pine. But the increase in bark beetle activity raised the question of whether bark beetles could produce offspring in Great Basin bristlecone if they were attacked.

In 2014, Bentz and her colleagues surveyed the entire range of the species and did not find a single Great Basin bristlecone pine with signs of a successful bark beetle

Limber Pine Restoration after the East Troublesome Fire

The East Troublesome Fire jumped the Continental Divide and burned through Rocky Mountain National Park (RMNP) in October 2020. The fire burned nearly 200,000 acres, including 29,000 acres in the park and 173 acres of limber pine stands. While 173 acres may not seem like a large area, limber pine plays an outsized role in maintaining biodiversity in the park and greater landscape, and only about 5,500 acres of limber pine remain in the park.

"We've been preparing for the invasion of WPBR and a disturbance like the East Troublesome Fire in the Park since 2008," says Schoettle, a founding member of the park's limber pine conservation program.

The program is a partnership between the park managers, Schoettle, and Kelly Burns, a USFS Forest Health Protection pathologist, that started because of declines in limber pine in RMNP related to severe drought, an expanding MPB outbreak, and the imminent spread of WPBR.

The collaborative program: (1) installed plots and monitors for forest health trends, (2) collects seeds from limber pines throughout the park for a genetic archive and for future planting needs, (3) conducted rust resistance screening trials, (4) protects trees from MPB attack annually, and (5) conducts other research activities. During the course of this work, WPBR was detected in the park in 2010.

The information gained from the program provided the foundation for Schoettle, Burns, and others to work with park managers to write a proactive limber pine conservation strategy for the park (adopted in 2015) and an expanded strategy for the Greater Rocky Mountain National Park Area that was finalized a year before the fire.

"The strategy was very much a proactive strategy to look at limber pine conservation before blister rust enters and dominates the landscape," says Chris Clatterbuck, the RMNP natural resource program manager. "Having a peer-reviewed conservation strategy helped us get the support and resources we needed for post-fire recovery planning, including a new partnership with American Forests."

attack. The researchers even infested Great Basin bristlecone and limber pines with MPB in their lab, and while thousands of adult beetles came out of the limber pine samples, only a few dozen emerged from the Great Basin bristlecone pine.

"We concluded that MPB don't like to attack Great Basin bristlecone pine. And if they do, then their offspring would die. It would be a kamikaze attack," Bentz says.

She believes the newly observed mortality occurring in parts of the Great Basin bristlecone range shows something novel is occurring in the relationship between the species and bark beetles.

"On Telescope Peak, warming temperatures allowed the beetles to build their numbers up so high in the limber pine that they spilled over into some of the stressed millennial age Great Basin bristlecone pine that was mixed in the limber stands," Bentz says.

Similarly, they believe that pinyon ips infesting drought-stressed pinyon pines at lower elevations were blown up to the Great Basin bristlecone pine stands at higher elevations.

Bentz says that while Great Basin bristlecone pine has strong natural defenses against bark beetles, climate change may tip the advantage to the beetles with increasing beetle numbers and drought stress on trees.

"The drought that is occurring in some areas is the worst in the last 1,200 years," says Bentz. "Great Basin bristlecone pine and bark beetles have likely had a long evolutionary arms race, and up until recently, Great Basin bristlecone pine had figured out how to defend itself. But it seems like climate change is disrupting that long-evolved relationship."

A Call to Action

Diana Tomback, a forest ecologist and conservation biologist with the University of Colorado Denver, has worked with whitebark pine for decades, going back to her discovery of the unique role of Clark's nutcracker as whitebark's primary seed disperser in the 1970s. More recently, Tomback has been working with federal agencies and tribal governments, as well as conservation nonprofits like the Whitebark Pine Ecosystem Foundation, which she helped found, and American Forests, on the National Whitebark Pine Restoration Plan. Tomback states that the Clark's nutcracker is key to the restoration plan for whitebark pine, because it can disseminate seeds, and thus genes for blister rust resistance, beyond restored stands.

Clark's nutcracker on a whitebark pine. Photo by D.F. Tomback

"We need the infrastructure to produce seedlings that are genetically diverse and have genetic resistance. We need to get these grown for outplanting," Tomback says. "If we're going to build resistance in the Sierra Nevada, where blister rust is not yet a major problem, we have to plant. We have to get genes for resistance in that population. In the northern Rockies, where we have many pockets where 100% of whitebark pine is dead, we have our work cut out for us."

In the special high-five issue of Forest Ecology and Management, the article summarizes management techniques based on the four conservation and restoration principles for whitebark pine and other high five species: (1) conserve genetic diversity, (2) promote WPBR resistance, (3) protect seed sources, and (4) deploy restoration treatments while mitigating climate change. These principles and their associated management or conservation actions can form the basis of a national restoration strategy, and Tomback says there is an urgent need for action.

"Many more trees need to be screened for resistance to achieve sufficient genetic diversity. We don't want to just plant seedlings from a handful of trees. We want to plant enough to rescue the genetic diversity as best we can from these species. Right now, our capacity is not great enough," Tomback says.

Robert Keane, an RMRS emeritus research ecologist and a co-author on the paper with Tomback, is a leading expert on strategies and techniques for whitebark pine management and restoration. Keane and co-authors also wrote a paper for the Forest Ecology and Management special issue expanding those management strategies to all the high-five species in a changing climate.

"We should protect and enhance resistance to the disease in whitebark pine, limber pine, and all the five-needle pines," Keane says. "That means finding the trees that are resistant to rust, collecting cones from those trees, growing seedlings from the collected seeds, and planting those rust-resistant seedlings. It also means protecting those sources of resistance from mountain pine beetles, which can come in and kill trees that are resistant to the rust."

Keane suggests saving these species entails ramping up management actions, which in addition to planting, include gene conservation, resistance screening, protecting seed sources, prescribed fire and silvicultural thinning to reduce competition, and monitoring for adaptive management. Restoration efforts using these principles, such as the Crown of the Continent (see text box page 9), are underway across the country, but researchers agree that current management efforts fall far short of the levels needed to save the species.

Crown of the Continent Ecosystem Whitebark Pine Restoration Strategy

The Crown of the Continent Ecosystem (CCE) straddles the continental divide in the North American Rocky Mountains, spanning nearly 18-million acres in Montana, British Columbia, and Alberta. The CCE is one of North America's most ecologically intact wildland landscapes, with a rich diversity of wildlife found nowhere else on the continent, from grizzly bear to woodland caribou. Whitebark pine is dramatically declining in the CCE because of a combination of blister rust, succession to more shade-tolerant conifers, and bark beetles, with greater than 90% mortality on some sites.

The CCE High Five Working Group formed in 2016 as a cross-jurisdiction, multistakeholder group with the mission to protect and restore whitebark and limber pine ecosystems. In 2019, the working group piloted a strategic approach for restoring whitebark pine on a smaller slice of the CCE that included Confederated Salish and Kootenai tribal lands, Glacier National Park, and the Flathead National Forest.

Melissa Jenkins, Flathead National Forest silviculturist (retired) who led the pilot effort, said the first step in the approach was determining the potential range where whitebark pine is capable of growing. Next, they narrowed that larger area down to core areas with the highest conservation value—where it's most important to restore. The core areas represent about 28% of the potential whitebark pine range across the pilot region (nearly 400,000 acres). Within those core areas, they considered existing site conditions and effects from blister rust, MPB, succession and climate change to determine where treatments were most likely to be successful.

Jenkins says that genetic principles were a major consideration when planning restoration treatments because of the high levels of mortality in the CCE. Rather than intact stands, whitebark in the area primarily exists in clumps or individual surviving trees on ridge tops. With the low tree density and declining genetic diversity in these populations, a downward spiral of genetic fitness could eventually result in the loss of the species.

The project is now beginning the hard work of implementing the plan with an emphasis on restoration treatments that create or protect "component" populations of adequate size and genetic diversity. Planting is the primary treatment being used, while direct seeding, prescribed burning, thinning, and MPB protection, also play important roles. Jenkins says managers are also counting on a natural ally of the whitebark pine.

"We're going to have to rely on the birds—Clark's nutcrackers—to connect and expand those populations," Jenkins says. "We need to work as a team with the Clark's nutcrackers to restore the species, because humans can't do it alone."

Jenkins says the most valuable contribution of the pilot study was the development of a flexible, data-informed decision-making process for species restoration that managers can apply consistently across large geographic areas, including the rest of the CCE and other areas outside of the CCE, as part of the National Whitebark Pine Restoration Plan. The approach has recently been expanded to include both whitebark pine and limber pine across the entire CCE, including those portions in Canada, and is guiding restoration planning and activities in many jurisdictions.

"We have the ability. We have the techniques. We've got the passion," says Keane. "There currently isn't the support and funding to grow and plant seedlings at the level needed for true restoration."

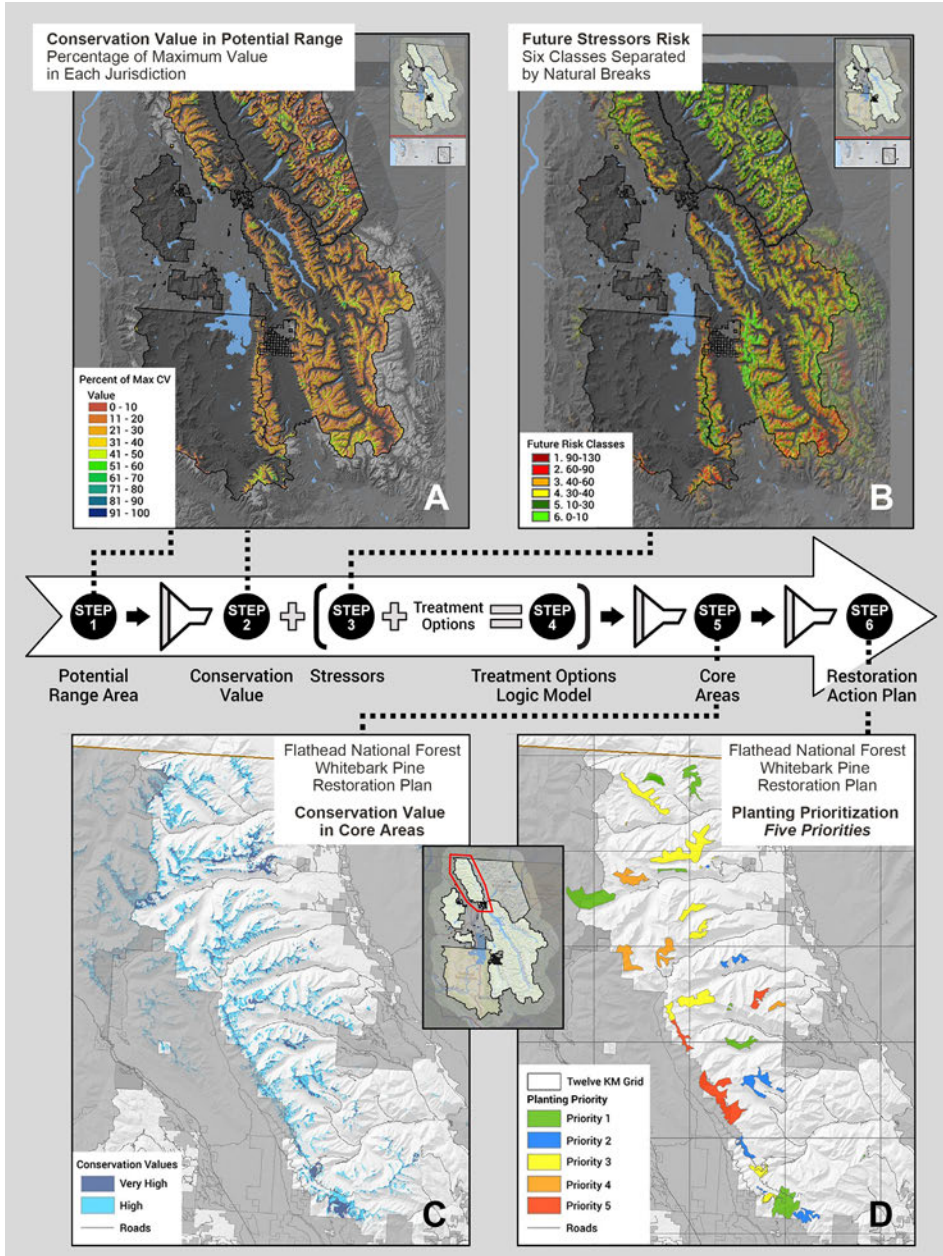
Building Resilience for the Long Term

Building high-five population resilience requires increasing diversity to support genetic resistance to immediate threats like blister rust and long-term adaptive capacity to the effects of climate change. It also requires active protection of invaluable, disease-resistant seed trees from disturbances like MPB and fire. The tools and methods for conserving and restoring high-five species are growing, as the recent Forest Ecology and Management special issue attests.

High-five researchers emphasize that protection and restoration of whitebark and limber pine, as well as proactive conservation of the other high-five species, is now more a matter of resources and strategic focus than science and know-how.

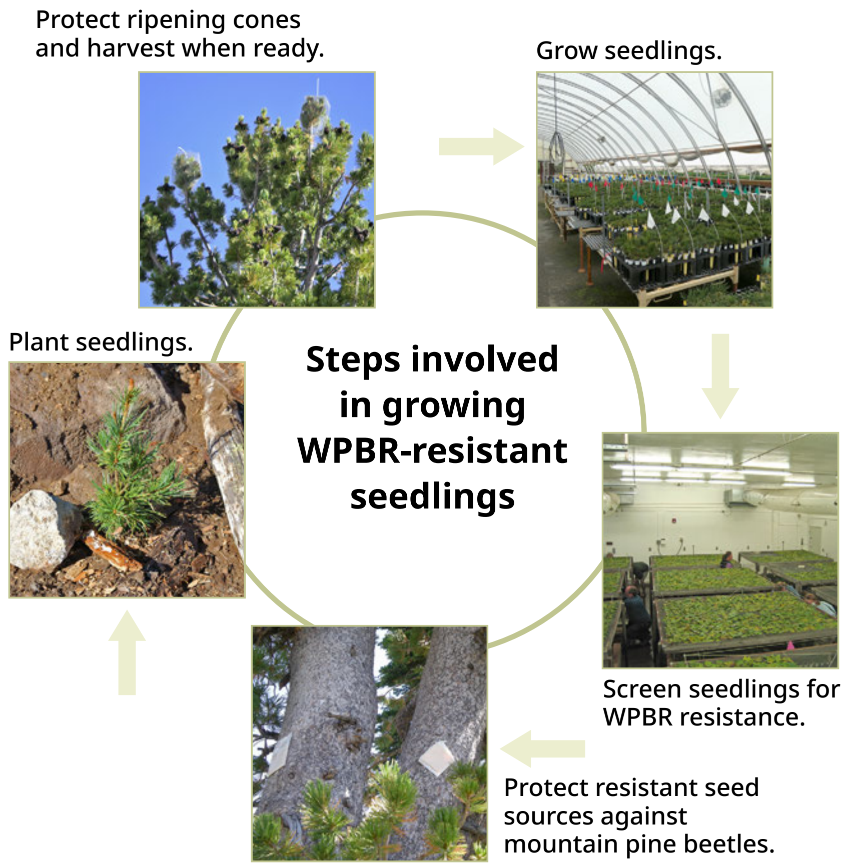
“All federal agencies have more on their plate than they can deal with—wildfires, climate change, and epidemics of disease and pests—but losing whitebark pine is huge, and it’s happening. And some of the other high-elevation, five-needle pine species are not far behind,” says Diana Tomback. “These ecologically important species are going down on our watch. But we know what must be done, and there is still time, if we make it a priority.”

Schoettle says she is optimistic researchers and managers can tip the balance with management for whitebark and other high-five species.



The six-step methodology for restoration planning of whitebark pine in the Crown of the Continent Ecosystem. Inset A: *Step 1. Establish potential range. Step 2. Quantify conservation value (CV).* Inset B: *Step 3. Quantify stressors (map combines all future stressors ratings (i.e., wildfire hazard, MPB risk, and future climate risk).* Center of Figure: *Step 4. Determine likelihood of treatment success based on stressor effects.* Inset C: *Step 5. Identify 20%-30% of potential range with highest CV as core area. “Very High” (i.e. CV1) and “High” (i.e. CV2) CV displayed within core areas (North Fork area of the Flathead NF).* Inset D: *Step 6. Implementation plan; planting treatment prioritization example with an overlaid 12 km grid (maximum distance recommended between component populations). From Jenkins et al. 2022*

"We are working in harsh environments in a very dynamic situation with climate change and all these other pests and pathogens," says Schoettle. "There are a lot of moving pieces. But we've got a good foundation in terms of evolutionary theory, population genetics, and silvicultural practices. So, I'm optimistic, but recovery and conservation are not going to happen on their own. We need to do more, and we need to do it faster."



From Tamm Review, Tomback et al. 2022. Top right photo by R. Sniezko; all others by D.F. Tomback

Key Findings

- Whitebark pine is declining rapidly because of increased mortality from WPBR and MPB and decreased rates of growth and regeneration. In 2019, about 54% of all standing whitebark pine trees were dead, an increase from 43% in 2009 and only 12% in 1999.
- Limber pine is showing signs of decline that are similar to that of whitebark 10 years earlier.
- Southwestern white pine has declined because of a series of large wildfires in southwestern U.S. that impacted large trees. Great Basin bristlecone, Rocky Mountain bristlecone, and foxtail pine have low rates of mortality, but their mortality will likely rise with greater exposure to stressors and disturbances.
- Although the high-five species are each threatened by the same stressors, their exposure and sensitivity to each stressor differs as well as their demographic patterns and vulnerabilities.
- High-five conservation and restoration actions must occur over multiple temporal and spatial scales of land management, from populations to national forests to regions to species' ranges.

Management Implications

- The four conservation and restoration principles for whitebark pine and other high five species are: (1) conserve genetic diversity, (2) promote WPBR resistance, (3) protect seed sources, and (4) deploy restoration treatments while mitigating climate change.
- The future outlook for each of the high-five species can be improved through timely restoration treatments and proactive management activities. Inaction risks other high-five species, especially limber pine, following the same declining trajectory as whitebark pine.
- Recognizing the unique features of each species enables identification of a suite of targeted management actions to address each species' vulnerabilities and improve their resilience and future outlook.
- Management actions must promote high-five pines' adaptation to WPBR and climate change as well as mitigate other mortality factors, including bark beetles, to successfully achieve the management goal of maintaining or restoring self-sustaining, genetically fit high-five populations across their ranges.
- The National Whitebark Pine Restoration Plan and the Crown of the Continent Restoration plan are flexible, data-informed decision-making processes that managers can apply consistently to U.S. and Canadian whitebark and limber pine forests.

Further Reading

Clark's nutcracker collecting seeds from a limber pine cone. Photo by D. Tomback

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Scientist and Manager Profiles

The following individuals were instrumental in the creation of this Bulletin:

Anna Schoettle is a research plant ecophysiologist with the Rocky Mountain Research Station. Her research focuses on building the scientific foundation and proactive approaches to accelerate the adaptation of five-needle pines to multiple interacting biotic and abiotic stresses in a changing climate.

Robert Keane is a retired supervisory research ecologist with the Rocky Mountain Research Station. His research is on the landscape ecology of ecosystem processes, especially disturbance, climate, and vegetation, and the scales at which these processes interact.

Barbara Bentz is a research entomologist with the Rocky Mountain Research Station. Her research focuses on understanding temperature response and adaptations of bark beetles and associated communities for increased understanding of population outbreaks in a changing climate.

Melissa Jenkins is a retired silviculturist with the Flathead National Forest and long-time board member of the Whitebark Pine Ecosystem Foundation. She has led pioneering efforts to restore whitebark pine in the northern Rockies, including the model Crown of the Continent Ecosystem Whitebark Pine and Limber pine Restoration Strategy.

Sara Goeking is a supervisory biological scientist with the Rocky Mountain Research Station. Her work seeks novel applications of Forest Inventory and Analysis data that will enhance our understanding of forest dynamics such as mortality, disturbance, and land use/land cover change.

Diana Tomback is Professor of Integrative Biology at the University of Colorado Denver. Her expertise includes the evolution, ecology, and population biology of bird-dispersed pines and their corvid dispersers; and the conservation and restoration of five-needle white pines in western North America.

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