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Preempting the Pathogen: Blister Rust and Proactive Management of High-Elevation Pines

An old bristlecone pine stands sentinel on a windswept, rocky slope in the Rocky Mountains. High-elevation five-needle pines are among the longest-living organisms on earth, and they are built to tough-it-out in harsh mountaintop ecosystems (photo by J.D. Coop, Western State Colorado University).

SUMMARY

White pine blister rust has been spreading through western forests since 1910, causing widespread mortality in a group that includes some of the oldest and highest-elevation pines in the United States. The disease has recently reached Colorado and is expected to travel through the southern Rockies. Although it cannot be contained, RMRS researchers and collaborators are developing proactive strategies that integrate conservation, ecology, and genetics to prepare ecosystems for invasion of the pathogen.

Genetic resistance occurs in a small percentage of individuals in each of the five-needle pine species that are susceptible to the rust. Researchers and managers are identifying how common this resistance is in forest stands and where resistance is located on the landscape by collecting seeds and screening seedlings exposed to the rust for signs of disease development. This information is integrated with new ecological research on population dynamics, climate interactions, and conservation activities to develop management strategies, which may include planting of resistant seedlings or creating regeneration opportunities near resistant trees. Rocky Mountain National Park, which was hit by the rust in 2010, will be one of the first adopters of the proactive management strategy to protect their limber pine populations. Managers with the U.S. Forest Service, other National Parks, and Canadian land management agencies are also putting the proactive approach into practice.

THE VALUE OF GRANDFATHER TREES

High-elevation five-needle pines are built for perseverance. A Great Basin bristlecone pine in California called “Methuselah” has orbited the sun more than 4,700 times as of this writing! Bristlecone pine and other high-elevation pines—whitebark, limber, southwestern white, foxtail, and Rocky Mountain bristlecone—are the very embodiment of resilience, toughing it out over eons on remote, exposed rocky mountaintops in blazing sunshine, drought, howling winds, and snowstorms. Slow-growing and tolerant of stressful conditions, they are only dominant in the harsh high-elevation environments that weed out their faster-growing competitors.

These species have great ecological and symbolic importance in North America as old, gnarled "grandfather" trees. They also have value in capturing and retaining snow on the ground by adding roughness and shade, and providing important food sources for wildlife, particularly the Clark's nutcracker and bears. High-elevation five-needle pines have strong aesthetic and social value. "These are trees that people feel an important bond with, because of both their age and their presence in many important recreation sites. People want to see these trees enduring for the long term on our landscape," observes Kelly Burns, a forest pathologist with the USFS Rocky Mountain Region, Forest Health Protection.

Unfortunately, five-needle pines are experiencing widespread mortality and reduced capacity for forest recovery due to the combined impacts of white pine blister rust, mountain pine beetle, dwarf mistletoe, and climate change. But there is hope. An interdisciplinary team spearheaded by Anna Schoettle, a Research Plant Ecophysiologist with the Rocky Mountain Research Station, is developing proactive management approaches that help ensure these valuable high-elevation ecosystems continue growing old trees into the future.

The large seeds of whitebark pine (shown here) and limber pine are an important food source for wildlife, particularly the Clark's nutcracker (photo by Robert Mutch, Ecosystem Photography).

Schoettle's partners in this important research include: Kelly Burns, forest pathologist with the USFS Rocky Mountain Region, Forest Health Protection; Richard Sniezko, geneticist at the USFS Dorena Genetic Resources Center in Oregon; Jun-Jun Liu, geneticist with the Canadian Forest Service in British Columbia, Canada; Patty Champ, research economist at RMRS; James Meldrum, research economist with the U.S. Geological Survey; Amy Angert, plant evolutionary ecologist with University of British Columbia in Canada; and others.

THE SPREAD OF WHITE PINE BLISTER RUST IN THE WEST

In 1998, a student working with Anna Schoettle was collecting data on limber pine ecophysiology in northern Colorado when she discovered trees with the telltale orange cankers of white pine blister rust, a fungal pathogen, for the first time in the State. Native to Asia and introduced to western North America in 1910 on a shipment of seedlings to Vancouver, Canada, this disease has spread like a stain across western forests, infecting all but one of the eight species of five-needled pines in the region. The rust has not yet reached the population of Great Basin bristlecone pine.

Schoettle was not particularly surprised by the pathogen's arrival, knowing that the disease had been found 10 miles across the border in Wyoming. It was, however, a clear message that her limber pine research goals needed to be reprioritized. "I thought, we can't just sit here and let our trees die when we know what this pathogen can do," she recalls.

Unlike many diseases that can be transferred directly from tree to tree, blister rust has a complex life cycle involving five spore stages and requiring an alternate host (mainly shrubs in the currant and gooseberry genus, *Ribes*). In affected forests, rust-colored fungal spores erupt by the billions in spring from cankers on infected trees and are blown by the

White pine blister rust canker on a limber pine branch (photo by A.W. Schoettle, U.S. Forest Service).

wind to infect currant and gooseberry bushes. Spores produced in the fall on the bushes travel in the breezes and infect new pines. The fungus enters a tree via its needles and spreads through the branches into the main stem, and eventually kills the tree.

Blister rust has caused significant damage in the northwestern United States, close to the epicenter of the disease introduction. Western white pine, once a prized timber species in the Northwest, now occupies only 5 percent of its historical acreage, and whitebark pine is in a steep population decline. It has been recommended for placement on the Endangered Species list. Without intervention, the high-elevation five-needled pine species of the southern Rockies and Great Basin will likely follow the same trajectory.

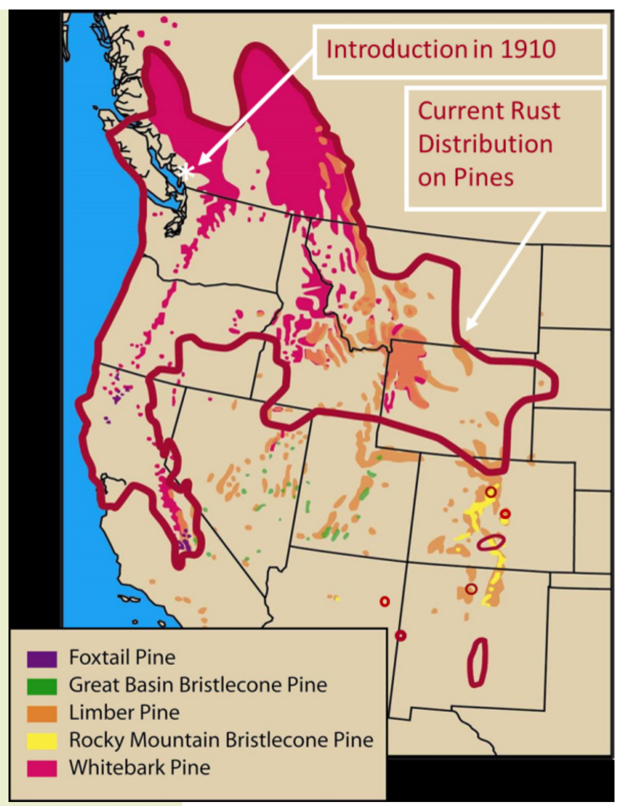
RESISTANCE IN THE FIVE-NEEDLE PINES

The one bright spot in this tsunami of orange spores is the discovery that every susceptible white pine species has at least some individuals that are genetically resistant to the disease. If researchers are able to estimate the frequency of these individuals and identify the resistant trees, it is possible to increase the numbers of their offspring in the forests *before* the pathogen arrives. This approach, called "proactive management," involves early intervention to mitigate the extent of damage from the rust and increase the ability of five-needle pine ecosystems to persist once the pathogen has arrived.

"Utilizing genetic disease resistance in wild populations to assess risk before invasion is novel," Schoettle explains. "Disease resistance in the past has been focused on breeding programs. My program's focus is on utilizing knowledge to accelerate the natural selection for resistance, while sustaining viable populations, under natural conditions in forest stands."

Genetic resistance to rust comes in two forms: partial and complete. Trees with partial resistance are able to slow the disease progression to some extent; in essence, the tree is able to survive and reproduce despite the infection. Trees with complete resistance are fully immune to the rust. However, complete resistance is under the control of a single gene (suspected to be unique in

White pine blister rust has slowly spread across western forests, infecting seven of the eight species of five-needled pines in the region and causing high levels of mortality. Only Great Basin bristlecone pine has not been found to be infected in the field at this time, although it is susceptible (figure by Schoettle and Sniezko).



Five-needle Pines of the Western US

Five-needle pine species in the western United States all have some individuals with partial genetic resistance to white pine blister rust. Several species (denoted with an asterisk) also have individuals with complete genetic resistance.

Lower-elevation western timber species

- Western white (*Pinus monticola*)*
- Sugar (*Pinus lambertiana*)*

High-elevation western species

- Whitebark (*Pinus albicaulis*)
- Limber (*Pinus flexilis*)*
- Great Basin bristlecone (*Pinus longaeva*)
- Rocky Mountain bristlecone (*Pinus aristata*)
- Southwestern white (*Pinus strobiformis*)*
- Foxtail (*Pinus balfouriana*)

Eastern species

- Eastern white (*Pinus strobus*)

Researchers are combing the forest for resistant trees, both in pine populations already infected with the rust and in populations where the disease has not yet hit. Jun-Jun Liu and colleagues are also developing molecular tools to help detect resistance. According to Liu, "a technique like marker assisted selection, which requires only needle collections rather than cone collections, followed by progeny tests can greatly accelerate the identification of resistant seed trees across the landscape."

Schoettle and her collaborators are also evaluating whether rust-resistant five-needle pines have different physiological traits than susceptible trees. Research on the physiology of resistant trees can shed light on how

each species), meaning there's a good chance the rust fungus could overcome complete resistance with one mutation.

The overall numbers of trees with resistance genes across the landscape is low. For example, it is estimated that when the disease first struck western white pine, only 1 in 10,000 had any type of rust resistance. Fortunately, the occurrence of resistant trees in mountaintop pine species of the southern Rockies appears slightly higher. Finding these individuals, researching the causes of rust-resistance, and increasing the prevalence of resistance in natural populations are key for sustaining healthy high-elevation pine ecosystems.

White pine blister rust requires an alternate host, usually shrubs in the ***Ribes*** *genus (pictured here below a Rocky Mountain bristlecone pine), for part of its life cycle (photo by A.W. Schoettle, U.S. Forest Service).*

resistant pines might respond to a variety of stressors, including climate change, and how this may influence their distribution in the future.

Schoettle's research suggests that resistant limber pine trees are more cold tolerant and respond to drought differently from nonresistant individuals. Further work is underway to determine if different drought responses could help or hinder survival of resistant pines in the field under drier conditions.

STACKING THE DECK WITH PROACTIVE MANAGEMENT

After the mountain pine beetle chewed its way through millions of acres of pine forests across the Rockies, we were left to wonder if there was something we could have done? It's hard to say after the fact, but with the white pine blister rust, there are some preemptive moves that can be made before the disease reaches high-elevation pine ecosystems. The goal of proactive management is to avert a crisis by preparing ecosystems for the arrival of agents of forest disturbance.

"We want to learn how we can modify the native ecosystem before an invasion so that it can transition into being functional more quickly after the fact," says Schoettle. The proactive strategy centers on increasing both the successful regeneration of pines on the landscape and the proportion of those pines that are rust-resistant before the population numbers are driven

Research technicians monitor natural regeneration to determine the factors that affect successful establishment and help guide decisions to plant rust-resistant pine seedlings or rely on natural regeneration (photo by A.W. Schoettle, U.S. Forest Service).

to critically low levels by the disease. Examples of proactive actions include:

- Conserving five-needle pines on the landscape and archiving their genetic diversity in seed gene banks;
- Discovering the baseline frequency and characteristics of disease resistance in pine populations;
- Promoting natural regeneration and planting rust-resistant seedlings;
- Discovering trees with durable resistance and encouraging their regeneration; and
- Coordinating with other management strategies, such as replanting efforts after wildfires, and integration of these strategies into Forest Plans.

The window of time to implement proactive management for white pine blister rust is relatively long, the earlier the resistance can be established on the landscape, the better. While it takes blister rust a minimum of 10 years—and often 20 to 30 years—to kill a large tree, maturation of young seedlings of these high-elevation pines can take many decades. If resistant trees are planted just as the rust arrives, many of the new trees would still be 15 to 20 years from producing a cone crop by the time diseased trees start to die.

Of course, planting before the rust reaches an area can prevent any interruption in the regeneration capacity of the forest. Schoettle adds,

KEY FINDINGS

- Five-needle pine species in high elevation ecosystems, which include some of the oldest trees on earth, are threatened by the spread of white pine blister rust. The rust has already caused widespread mortality in much of the western United States.
- All of the five-needle pine species have a small number of individuals that are resistant to the rust, and researchers have been working to identify these trees to learn about the genetic underpinning of resistance and design management plans that increase the prevalence of resistant trees on the landscape.
- Resistant trees that remain after a blister rust invasion may be too few and too far apart to be self-sustaining without intervention.
- Proactive management of high-elevation pine ecosystems seeks to intervene before the blister rust arrives by increasing the number of resistant pines in the landscape. The goal is to allow pine populations to sustain themselves over the long term in the presence of the pathogen.

"But, if we wait to go in after the trees are dead and then plant, it will be 50 years before they produce any cones and can provide for natural forest regeneration." Even if the resistance status of a local seed source is unknown, it may still be helpful to use these seed sources to increase the number of seedlings on the landscape; it's possible that some resistant individuals are in the bunch.

What if we don't go in and plant at all? When the rust kills the susceptible trees, the resistant trees that remain will be the ones to perpetuate the species—a 'survival-of-the-fittest' scenario played out over the course of only a few decades. However, the low numbers of trees with resistance genes across the landscape could hamper regeneration from the remaining trees. Survivors may produce too few seeds for successful seedling establishment to occur. Low numbers in the pine populations also make them vulnerable to being locally wiped out by other disturbances, such as wildfires and mountain pine beetles.

For these reasons, the consequences of doing nothing could be that the few remaining rust-resistant pine trees may not be able to sustain a population or the species over the long term. The loss of five-needle pines would cause major disruptions to mountaintop ecosystem functioning, watershed protection, and the local wildlife populations.

ROCKY MOUNTAIN NATIONAL PARK: AN EARLY ADOPTER OF PROACTIVE MANAGEMENT

White pine blister rust was first detected in Rocky Mountain National Park (RMNP) in 2010, but forest managers were already preparing for it. "Understanding the blister rust threat has been a concern for the park for decades," says Ben Bobowski, Chief of Resource Stewardship. Schoettle and her collaborators started work with park managers in 2008 to lay the scientific foundation for a management strategy for limber pine, the only five-needle pine found in RMNP.

Genetic information on five-needle pine populations in RMNP is helping guide the scientists and managers towards the best steps to take next. Researchers found that limber pines in RMNP have relatively high levels of complete resistance—the type that can be overcome with a single genetic mutation in the rust. In terms of management, planting seedlings with only this type of resistance could accelerate the proliferation of the more virulent rust.

Schoettle comments, "The early knowledge of resistance patterns in the park is helping to guide how we proceed. For now, we are recommending the planting out of seeds and seedlings from the greater population—which will include both resistant and susceptible trees—to increase the number of limber pines in the landscape while we work to identify the more durable partial resistance."

Schoettle and her collaborators prepared a limber pine conservation strategy for RMNP, which is the first comprehensive proactive management plan based on the

Rocky Mountain National Park volunteer staples verbenone pouches to a limber pine seed tree to repel mountain pine beetle attack (photo by A.W. Schoettle, U.S. Forest Service).

AND WHAT DOES SOCIETY THINK ABOUT PROACTIVE MANAGEMENT?

It is one thing to restore a damaged ecosystem after the fact, and another thing entirely to go into an area that is yet unaffected and start planting selected (in this case, rust-resistant) tree seedlings, particularly in wilderness areas. As such, an important aspect of proactive management is gauging community support for the strategy.

Rocky Mountain Research Station scientist Patty Champ and U.S. Geological Survey scientist James Meldrum worked with collaborators to conduct surveys and assess whether a random survey of citizens in the west thinks it is worth spending tax dollars on proactive management. An overarching finding was that these high-elevation pines have “existence value,”, meaning people value the trees and want to see them preserved for future generations, whether or not they have or will ever see them in person.

And people are willing to pay to protect the pines. On average, households in the western United States are willing to pay about $150 to improve the resiliency of high elevation forest to the threat of white pine blister rust.

science foundation they developed. “Anna has given us a way forward, and we are looking forward to implementing this strategy at the Park,” says Bobowski, adding, “We are already using some pieces of her plan, such as protecting limber pine seed sources for future studies and considering when and where we might plant limber pine after a fire.” Work by Schoettle and her colleagues in RMNP even helped protect rust-resistant trees from mountain pine beetle attack using phytochemicals that repel the beetles.

A group of international scientists visit the Rocky Mountain bristlecone pines in the Mount Goliath Research Natural Area (CO) during the 2014 IUFRO Conference hosted by RMRS in Fort Collins. High-elevation pine ecosystems are facing threats from climate change, white pine blister rust, beetle epidemics, and wildfire, but proactive management today can help ensure a future for five-needle pine species (photo by R.A. Sniezko, U.S. Forest Service).

MANAGEMENT IMPLICATIONS

- High-elevation ecosystems not yet hit by white pine blister rust are good candidates for proactive management, such as intentionally planting rust-resistant trees to increase ecosystem resilience.
- In pre-infection areas where resistant trees have not yet been identified, it is important to protect seed sources and conserve seeds for their potential for adaptive and resistant genes.
- Estimating the frequency of rust-resistant five-needle pines in high elevation areas should be a priority so that impacts of the rust can be predicted and management plans can be developed.
- Communication and feedback between managers and researchers will be important in rust-infected areas with proactive management strategies in place so that the effectiveness of the strategy can be evaluated and modified as needed.

Researchers also found that people do not have a strong preference for proactive versus reactive management, and that they trust researchers and managers to make the appropriate calls based on their expertise.

THE WAY FORWARD

High-elevation pine forests, under the threat of multiple stressors, serve as an excellent flagship to shift the focus away from crisis management and toward proactive management that provides for ecosystem resilience. Along with RMNP, forest managers with the U.S. Forest Service, other National Parks, and Canadian land management agencies are putting the proactive approach into practice. According to Schoettle, "This approach has changed how managers see white pine blister rust in high-elevation forests. They now recognize that the situation is not hopeless and they can influence the outcome of the invasion with focused, early intervention." The future of high-elevation five-needle pines is not yet written, so managers should feel empowered to influence ecosystem resilience. Decisions today can increase the chances that these species persist and young trees of today can become long-lived sentinels in the centuries to come.

WRITER'S PROFILE

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SCIENTIST PROFILES

The following scientists were instrumental in the creation of this Bulletin.

ANNA SCHOETTLE is a Research Plant Ecophysiologist with the U.S. Forest Service's Rocky Mountain Research Station in Fort Collins, Colorado. She earned her MSc from Cornell University and PhD from the University of Wyoming. Anna's main research goal is to provide a solid scientific foundation for proactive management to facilitate a shift from crisis management of natural resources to proactive management for sustained ecosystem function and resiliency. She uses an integrated interdisciplinary approach to further the scientific knowledge and inform land managers. Anna's work on proactive management earned her team the Excellence in Invasive Species Innovative Control and Management award from the U.S. Forest Service's National Invasive Species Program in 2011.

KELLY BURNS is a Forest Pathologist with the USDA Forest Service, Forest Health Protection in Golden, Colorado. She has an MS degree in Integrated Forest Protection from Oregon State University. Her work focuses on detection, monitoring, and management of forest diseases, particularly white pine blister rust. Over the past 15 years, Kelly has actively collaborated with Rocky Mountain Research Station and Colorado State University on numerous research studies that build the science foundation to develop management strategies to protect, sustain, and restore high elevation five-needle pines.

RICHARD SNIEZKO is a Geneticist with the U.S. Forest Service Dorena Genetic Resource Center in Oregon. He earned his PhD from North Carolina State University in 1984. He began working in disease resistance with the Dorena Genetic Resource Center in 1991 and oversees several operational forest tree resistance programs.

PATTY CHAMP is a Research Economist with the Rocky Mountain Research Station's Human Dimensions Program. Her work focuses on nonmarket valuation methods, allocation mechanisms for recreational opportunities on public lands, and collaborative social science of homeowner's wildfire risk. Patty received her PhD in Agricultural Economics from the University of Wisconsin-Madison.

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