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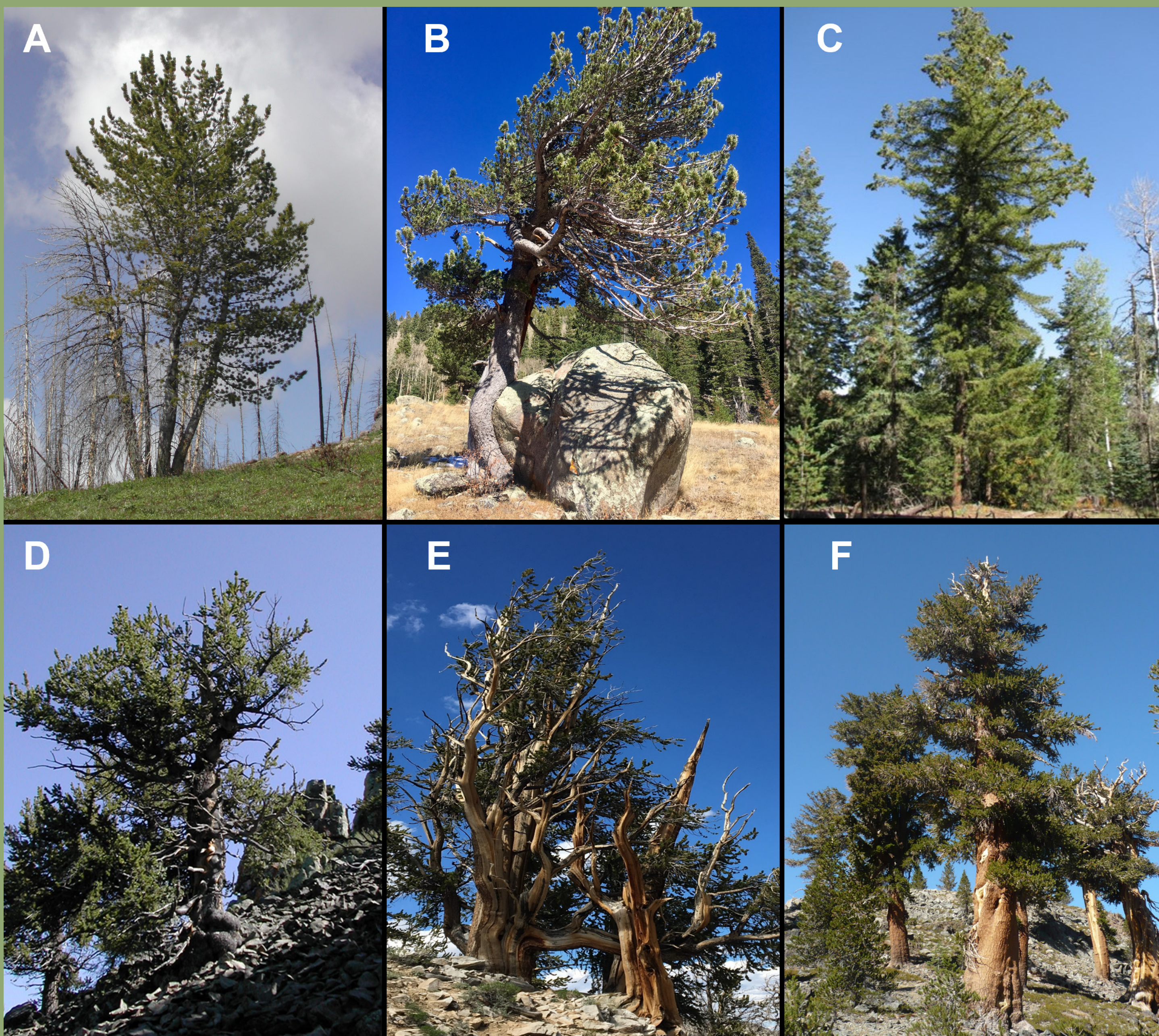
nutcracker notes

JOURNAL OF THE WHITEBARK PINE ECOSYSTEM FOUNDATION



This issue heralds a new era for the Foundation as we expand to include all High Elevation Five-Needle White Pines

OUR MISSION

The Whitebark Pine Ecosystem Foundation is a science-based nonprofit organization dedicated to counteracting the decline of whitebark pine and enhancing knowledge of its ecosystems.

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COVER:
Collage of photos of the High-5 species. A) whitebark pine; B) limber pine; C) southwestern white pine; D) Rocky Mountain bristlecone pine; E) Great Basin bristlecone pine; F) foxtail pine. Photo credits: A, D, E: A.W. Schoettle; B: C.T. Holtz; C; K.M. Waring; F: S.T. McKinney. From Schoettle et al., 2022.

David Neale

WHITEBARK PINE
ECOSYSTEM FOUNDATION

CHAIR'S MESSAGE

This issue of *Nutcracker Notes* features the expansion of WPEF's mission to include all the high elevation white pines of western North America. Since its founding, WPEF has focused nearly all its effort on whitebark pine due to its threatened and potentially endangered status. These efforts culminated in December 2022 when the US Fish and Wildlife Service listed whitebark pine as a threatened species. Now the enormous and challenging work of restoring whitebark pine to its ecological importance in the high elevation mountain environment begins. The National Whitebark Pine Restoration Plan led by Diana Tomback will be completed this year and the WPEF will transition its efforts to an implementation phase of the plan. Whitebark pine will remain the priority species for the WPEF; however, WPEF now recognizes that the five other high elevation white pines are also at risk due to white pine blister rust and changing climate (for descriptions see the Schoettle article on page 4). Thus, it is incumbent that WPEF focus some of its attention on these sister species. To successfully address this expanded mission, the WPEF will have to expand its regional scope, scientific and forest management experience, and membership. The rate at which this expansion will occur is in part dependent on funding for our programs and staff. A first significant step in this direction is the appointment of Julee Shamhart as the first Executive Director of the WPEF. As funding develops, we will seek to hire additional staff members to be a part of Julee's team. This transition for the WPEF is both exciting and challenging, but as the Chair of the Board of Director's I am fully committed to this transition and continuing our work to conserve and restore the high elevation white pines of the North American west.

David B. Neale

Director, Whitebark Pine Ecosystem Foundation
Distinguished Professor Emeritus

Randy Moody

CANADIAN PRESIDENT'S REPORT

The Canadian whitebark pine scene has been very active over winter and will continue to be through 2023. The BC Government has been very active in recovery work, ski hill certification has taken off, the Foundation is developing a number of training initiatives, and the annual science meeting is planned for Revelstoke this fall.

I am perhaps belatedly mentioning this but the BC Government has tagged Francis Iredale with managing recovery in BC; he has been instrumental in getting a number of large planning and outreach projects implemented including supporting the Crown Managers Partnership in restoration mapping, promoting extensive outreach with the forestry sector, and general support of several other whitebark pine recovery projects. Each month Fran hosts a roundtable discussion open to all practitioners, a great resource for anyone in Canada working on whitebark pine recovery, contact Francis to get added to the call.

The ski hill certification group would like to announce Panorama Mountain Resort located near Invermere is the first whitebark pine friendly ski resort certified in Canada; this certification comes several years after Sorcerer Lodge, a backcountry lodge near Rogers Pass was certified for their work with whitebark pine. Panorama has been a great ally in whitebark pine recovery facilitating cone collections, hosting workshops, seedling planting, and conducting glading in a whitebark pine positive manner. Further, Nelson writer Jayme wrote and article for Conde Naste Traveller about the whitebark pine at Panorama: https://www.cntraveler.com/story/in-british-columbia-skiers-and-forest-conservationists-work-in-tandem.

The Foundation recognizes that to recover the species across its entire Canadian range we are going to need to build a larger workforce to assist with this endeavour. To support this the Foundation will be delivering a series of training events in BC and Alberta this spring and summer, watch our website for information on these initiatives. Further, thanks to Parks Canada support, a number of tree climber trainers were certified in March to assist training additional personnel and work in expanding the labour pool for this technical side of cone collection.

Finally, mark your calendars for the annual science meeting from October 11-14 in Revelstoke BC. We pushed the meeting a little later this year recognizing that many practitioners are in the throes of tying up field work in September so wanted to add a little breathing room to your schedule. Plus, we are bookending the event with field trips which may be combined with your travel to and from the event, watch the Foundation website for more info on logistics and we certainly look forward to seeing everyone this fall!

Randy Moody

COVER STORY

Mountain top sentinels

Anna W. Schoettle
Rocky Mountain Research Station, US Forest Service

The High-5 comprise a subset of a unique group of related white pine species in the subgenus Strobus that grow across the high mountains of western North America. They include whitebark pine (*Pinus albicaulis*), limber pine (*P. flexilis*), southwestern white pine (*P. strobiformis*), Rocky Mountain bristlecone pine (*P. aristata*), Great Basin bristlecone pine (*P. longaeva*), and foxtail pine (*P. balfouriana*) (Fig. 1). These species grow in small groups on ridges as well as components of extensive forest communities. They have a disproportionally large effect on ecosystem functioning and biodiversity relative to their abundance (i.e., serving as keystone species) and they often define ecosystem structure and functional dynamics (i.e., serving as foundation species). Most of the High-5 can grow in harsh habitats providing critical slope stabilization and watershed protection in high mountain areas. They also add roughness to otherwise barren slopes which contributes to snow capture and slows snowmelt dynamics.

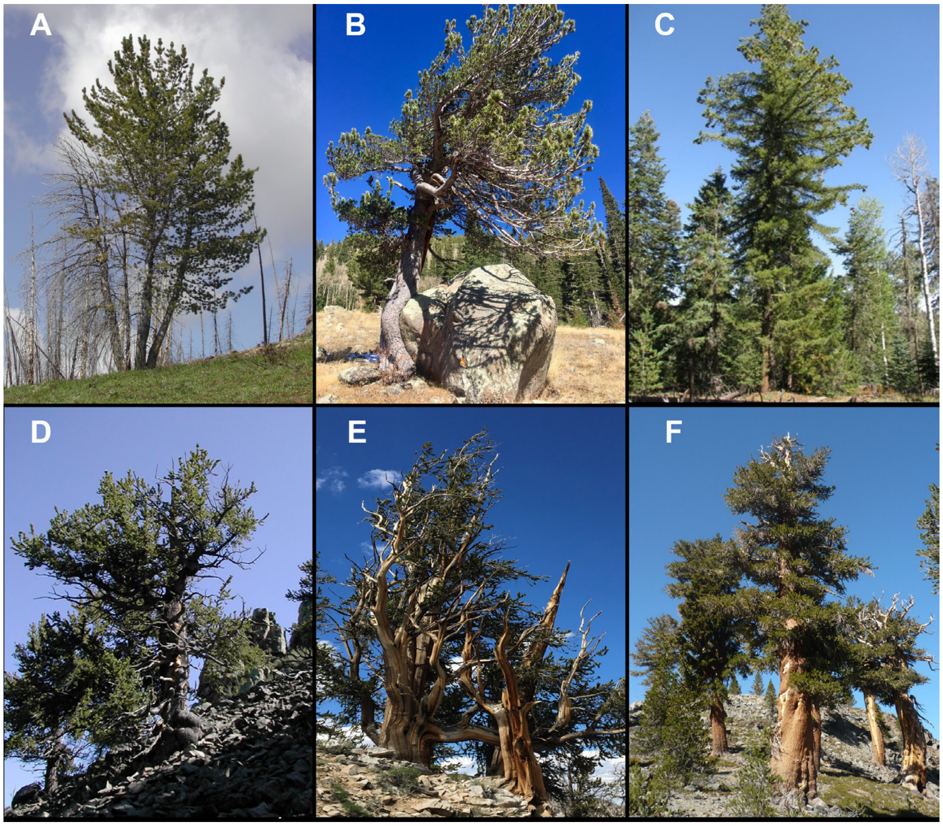

Figure 1. Collage of photos of the High-5 species. A) whitebark pine; B) limber pine; C) southwestern white pine; D) Rocky Mountain bristlecone pine; E) Great Basin bristlecone pine; F) foxtail pine. Photo credits: A, D, E: A.W. Schoettle; B: C.T. Holtz; C; K.M. Waring; F: S.T. McKinney. From Schoettle et al., 2022.

Both whitebark pine and limber pine have broad latitudinal distributions in the upper subalpine and alpine treeline zones (Fig. 2). Limber pine has a wider elevational distribution than whitebark pine and in portions of its distribution extend down to the lower grassland treeline. The habitats that support whitebark pine are cool and water availability is strongly driven by snow and early summer moisture with lower precipitation in July and August. The environments that support limber pine are diverse but tend to be warmer in the summer and have lower precipitation year-round than those supporting whitebark pine. Compared to the other High-5 species, limber pine is likely one of the most drought-tolerant. Limber pine is the only High-5 species whose distribution overlaps with each of the other High-5 species.

In southern Colorado, New Mexico, and Arizona, limber pine and southwestern white pine hybridize and ultimately the complex is

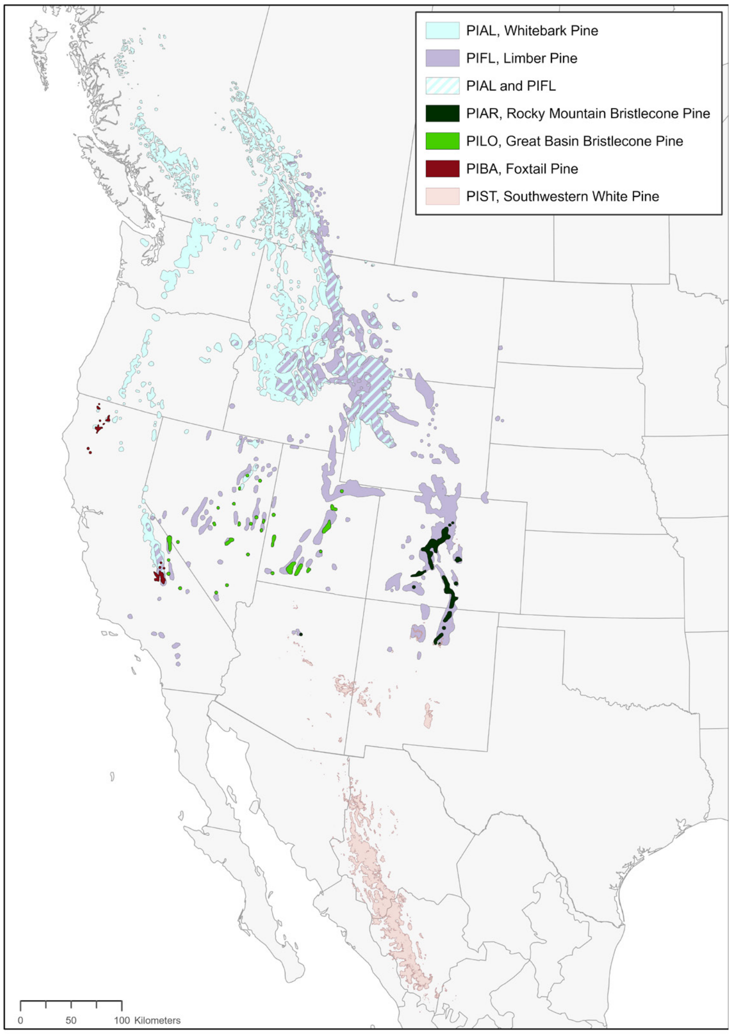

Figure 2. Distribution of the High-5 species in western North America. See Schoettle et al. 2022 for sources.

Figure 3. Rocky Mountain bristlecone pine krummholz above treeline in Colorado. The prevailing winds blow from left to right in this photo. Photo by AW Schoettle

replaced by southwestern white pine farther south and into its core range in northern Mexico. Southwestern white pine is an important component of the mixed-conifer forests upslope from pure ponderosa pine (*P. ponderosa*). It does not reach alpine treeline elevations. The signal of the North American Monsoon is strong in U.S. habitats of southwestern white pine; precipitation minimums occur in April through June and maximums in July through September. Compared to limber pine, it tends toward faster growth, reaching greater size, and often maintaining better form.

The final three High-5 species (Rocky Mountain bristlecone pine, Great Basin bristlecone pine, and foxtail pine) are in Subsection Balfourianae Engelm within the foxtail section (Parrya) of the subgenus Strobus. Rocky Mountain bristlecone pine and Great Basin bristlecone pine were distinguished as separate species in 1970 and have no overlap in their distributions (Fig. 2); prior to 1970, both species were called *P. aristata*. The core distribution for Rocky Mountain bristlecone pine is in central Colorado; its distribution extends into New Mexico with a disjunct population in northern Arizona. Rocky Mountain bristlecone pine grows in subalpine habitats in extensive forests, small stands, and as isolated trees on rocky outcrops. In some locations, it forms spreading krummholz mats above treeline (Fig. 3). Like southwestern white pine, Rocky Mountain bristlecone pine habitats have precipitation minimums in June and peaks in July and August because of the monsoon, though rainfall is lower, and late summer precipitation tends to be less reliable year-to-year.

Great Basin bristlecone pine grows on isolated mountain ranges and sky islands in Utah, Nevada, and the White Mountains of eastern California. Great Basin bristlecone pine habitats are warmer and drier than those of Rocky Mountain bristlecone pine, with only a weak pattern of late-summer precipitation and less late-winter snow than environments supporting whitebark pine or limber pine.

Foxtail pine has the most restricted distribution of the High-5 species. The distribution is disjunct with one portion in the Klamath Range in northern California and the other 500 km south in the southern Sierra Nevada (Fig. 2). The two populations are fundamentally different in structure, composition, and diversity. In the north, foxtail pine is the dominant tree on isolated peaks and often occurs in mixed subalpine forest communities that can include whitebark pine. In the south, foxtail pine usually forms extensive low-diversity stands where it can occur with whitebark pine, limber pine, and other species. The climate is warmer and wetter for the northern habitats than for those in the south.

All of the High-5 species are slow growing which hinders their ability to compete with faster-growing co-occurring trees, often leading to their replacement over time on mesic sites. The High-5 however tend to be more tolerant of cold arid conditions than other conifers enabling them to occupy dry exposed sites where other species cannot. It is on these dry harsh sites that they have earned the reputation as symbols of perseverance and are recognized and appreciated for their contorted artistic forms clinging to wind-exposed ridges and defining alpine treeline (Fig. 4). On these harsh sites, the High-5 can escape stand-replacing fire and survive for millennia. A Great Basin bristlecone pine tree, named "Methuselah", is among the oldest living non-clonal organisms on earth with an estimated age of over 4,700 years. Foxtail, Rocky Mountain bristlecone, limber, and whitebark pines can also reach impressive life spans (approximately 3,000, 2,500, 1,660, and 1,270 years, respectively).

Figure 4. Wind-sculped bristlecone pine trees near treeline. Photo by AW Schoettle

Figure 5. Rocky Mountain bristlecone pine shoot showing annual needle cohorts with variable needle lengths. Note the resin dots on the needles, a trait distinctive to this species. Photo by AW Schoettle

Most of the High-5 have dense wood, a consequence in part of slow growth, that resists rot and contributes to their longevity. The growth rings of these species record climate fluctuations providing us with a method to reconstruct past climates and detect more recent warming trends.

Slow growth also limited annual shoot extension and the number of new needles produced per year on a shoot. However, the High-5 can regulate how many cohorts of needles are retained and accumulated to form a full crown of photosynthetically functional needles (Fig. 5). Needles can survive on the High-5 routinely for about 7-15 years and up to 33 years for Great Basin bristlecone pine, the longest-lived leaves of any plant species on record. All the High-5, except southwestern white pine, offer dramatic examples of partial cambial dieback in older trees, characterized by a strip of dead bark extending from dead roots to dead branches. Partial cambial dieback is hypothesized to contribute to the exceptional longevity of individuals by effectively isolating damaged roots, stem or branches from remaining healthy tissues and thereby maintaining a favorable photosynthetic to non-photosynthetic tissue ratio. At its most extreme, a tree may have only a thin strip of live bark connecting a live root and branch supported on the dead remains

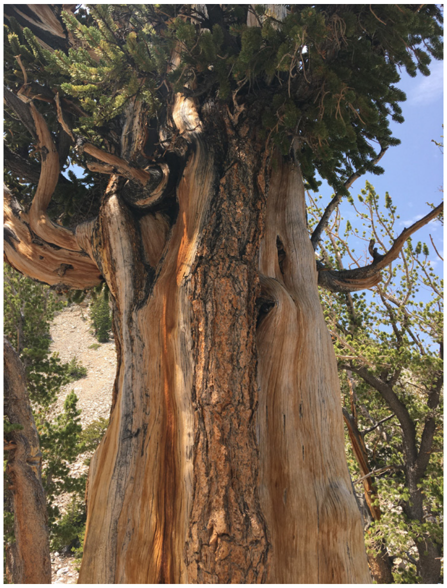

Figure 6. An example of partial cambial dieback on Great Basin bristlecone pine. Note that most of the cambium has died back leaving only a narrow strip of live bark running up the center of the stem supporting the live branches above. Photo by AW Schoettle

Figure 7. Healthy cone crop on a branch of southwestern white pine. Photo by AW Schoettle

Figure 8. A whitebark pine cone that has been shredded by a Clark's nutcracker reveals the large wingless seeds. Photo by AW Schoettle

of the formerly large tree (Fig. 6). Because the wood is so dense, the dead portion of a tree can stand and serve as a scaffold for many years.

The consequences of the same life history traits that lead to longevity (e.g., slow growth and stress-tolerant) result in slow development to reproductive maturity, often taking up to a century for a tree to produce a full cone crop (Fig. 7). Whitebark, limber, and southwestern white pine produce large wingless (or near wingless) seeds that rely on Clark's nutcrackers for long-distance dispersal. Whitebark pine, unlike limber and southwestern white pine, has seed cones that don't naturally open upon drying. A mutualism between whitebark pine and Clark's nutcracker has developed where Clark's nutcrackers not only eat and disperse the seeds but also dissect the seeds from the closed whitebark pine cones (Fig. 8). Clark's nutcrackers often cache more than one seed in a location, and if not retrieved, pilfered, or eaten, can lead to a cluster of seedlings (Fig. 9) that mature into a multi-stem growth form (see Fig. 1A). Both Rocky Mountain and Great Basin bristlecone pine species and foxtail pine have small, winged seeds that are primarily dispersed by wind, but Clark's nutcrackers can also cache these seeds on occasion. Squirrels and rodents cut cones from the crowns of the High-5 species for their own consumption and their cone caches can be raided by other animals, including bears (Fig. 10), with implications throughout the food web.

Figure 9 and 10. A cluster of young whitebark pine seedlings that likely originated from a seed cache forgotten by a Clark's nutcracker (left), and grizzly bear scat full of undigestible whitebark pine seed coats (right). Photos by AW Schoettle

Bird dispersal enables seeds to be transported to areas distant from the seed tree and can extend above treeline or into the interior of large stand-replacing disturbances that are beyond the dispersal distance of wind-dispersed seed. Consequently, seed dispersal affects the patterns of regeneration for a species and the genetic connectivity of populations. The High-5 tend to be early seral species but are generally slow to recolonize suitable habitats after disturbance. These species rely on tree longevity for the persistence of populations. Their slow growth, delayed maturity, and protracted regeneration dynamic limit population turnover and therefore their capacity for rapid adaptation to novel stressors. These spectacular long-lived, mountain-top sentinels that have been supporting the biodiversity of high-elevation ecosystems and recording the earth's climate in their growth rings for eons are now facing new challenges in the Anthropocene.

Prepared by Anna W. Schoettle, Rocky Mountain Research Station, Ft. Collins, CO. Adapted in part from Schoettle, AW, KS Burns, ST McKinney, J Krakowski, KM Waring, DF Tomback, M Davenport. 2022. Integrating forest health conditions and species adaptive capacities to infer future trajectories of the high elevation five-needle white pines. Forest Ecology and Management *521, 120389. (https://www.fs.usda.gov/research/treesearch/64862)*

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Strategically restoring the High Five Pines: one "plan" will not fit all

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Editor's Note: *The Whitebark Pine Ecosystem Foundation (WPEF) has always provided a forum for important information on all High Elevation Five-Needle White Pines and not just whitebark pine, especially in* Nutcracker Notes, *our annual Science and Management Conferences, and the two High Five Conferences. Now, the mission of the WPEF officially includes all the High Elevation Five-Needle White Pines of the U.S. and Canada. See accompanying article by A. W. Schoettle for more information on High Five ecology and distribution.*

The group of pines referred to by managers and researchers as High Elevation Five-Needle White Pines (Genus Pinus, Subgenus Strobus, Sections Quinquefolia and Parrya), or "High Five pines" for short, contribute important forest community diversity to our western landscapes, comprise high elevation habitat and a food source for wildlife, protect watersheds, and are associated with some of the most iconic scenary in the western U.S. and Canada. The High Five pines include whitebark (*Pinus albicaulis*), limber (*Pinus flexilis*), southwestern white (*Pinus strobiformis*), Rocky Mountain bristlecone (*Pinus aristata*), Great Basin bristlecone (*Pinus longaeva*), and foxtail pine (*Pinus balfouriana*). Only southwestern white pine has been commercially harvested for its wood; thus, the High Five pines are predominantly valued for their ecological roles in the upper forest zones across the West and Southwest. Three of the pines (whitebark, limber, and southwestern white) have large, wingless seeds and depend on either Clark's nutcrackers (*Nucifraga columbiana*) or an opportunistic mix of nutcrackers, jays, and forest rodents for seed dispersal (limber and southwestern white pine); and the bristlecones and foxtail pine have small, winged seeds that can be dispersed from trees by wind but are sometimes dispersed directly by nutcrackers and jays.

The High Five pines share a number of ecological affinities: they occupy the upper forest elevations; inhabit steep, rocky slopes; tolerate shallow, poorly developed soils; exhibit moderate to high shade intolerance; tolerate arid, windy conditions; and may require disturbance for renewal of successional or mixed communities. Under the harshest conditions on exposed sites, all the High Five pines except southwestern white pine grow slowly, assume twisted or wind-sculpted growth forms, and may achieve ages of a thousand or more years. The High Five pines have been tracking major climate changes and exhibiting distributional shifts throughout the Pleistocene cycles of glaciation and inter-glacial periods and through the Holocene (Anthropocene)—the last eleven thousand years. This past century, however, has brought to the High Five a challenging suite of largely anthropogenic threats to which few are well-adapted: the exotic and often lethal fungal pathogen Cronartium ribicola, which causes the disease white pine blister rust; outbreaks of mountain pine beetles (*Dendroctonus ponderosae*), which kill mature trees; changing fire regimes; and, climate warming, which alters pine distributions, fuels pine beetle outbreaks, and enables blister rust to occur in regions and at elevations once thought too climatically extreme for the pathogen. All threats vary in intensity and consequence across the ranges of the High Five and by species, but species also differ in their resilience to these threats. Whereas restoration strategies for the High Five pines may be similar in their objectives, they will differ in the steps required for their development.

Whitebark Pine Restoration At The Leading Edge

Among the High Five pines, whitebark pine has been most heavily impacted by blister rust and recent mountain pine beetle outbreaks (Fig. 1). On January 17, 2023, whitebark pine was officially listed as threatened by the U.S. Fish & Wildlife Service under the Endangered Species Act. It had been listed as Endangered in Canada a decade earlier under the Species at Risk Act. The precipitous decline of whitebark pine and the growing need for restoration action was first signaled by the 1989 conference, sponsored by the USDA Forest Service Rocky Mountain Research Station, Restoring Whitebark Pine Ecosystems, which provided a forum for researchers and managers to showcase nascent restoration treatments and strategies. The conference led to the contributed volume, *Whitebark Pine Communities: Ecology and Restoration*, edited by D.F. Tomback, S.F. Arno, and R.E. Keane, and published by Island Press in 2001. Since 2001, a number of restoration plans, both regional and range-wide, including a 2017 draft recovery strategy for whitebark pine in Canada under the Species at Risk Act, were written for whitebark pine (see Table S1, Tomback et al. 2022 for a list of plans). In parallel, scientists and managers have been developing conservation actions and restoration treatments for whitebark pine over the last two decades. During this time, USDA Forest Service facilities have been screening whitebark pine and the other High Five pines to identify seed source trees with 'usable' genetic resistance to blister rust and

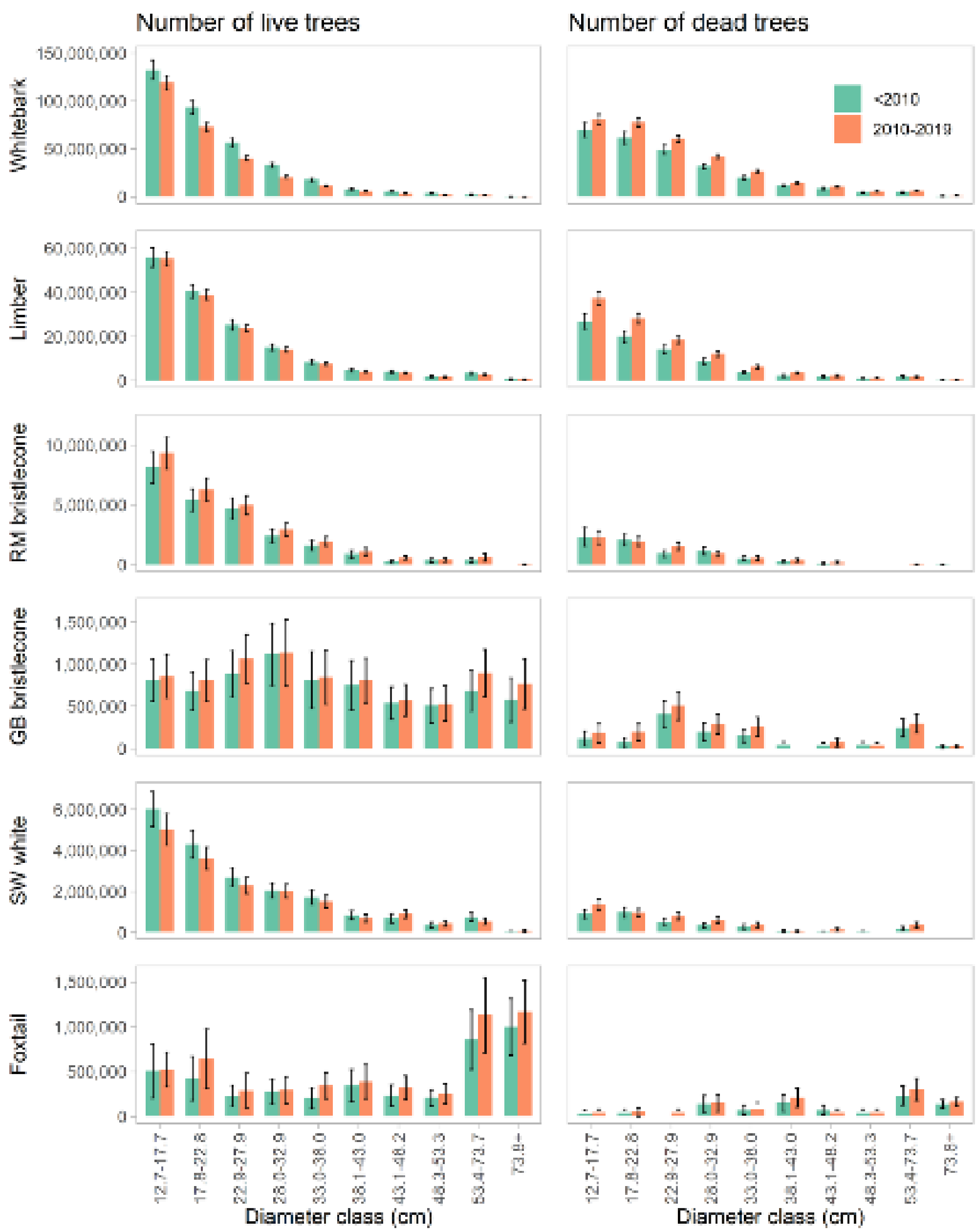

Figure 1. Figure 2 from Goeking and Windmuller-Campione (2021) showing trends in mortality for High Five pines ≥ 12.7 cm in diameter at breast height. Data source was the USDA Forest Service FIADB, Forest Inventory and Analysis program. The graphs depict the number of live and dead trees by species and diameter class, and compare data obtained prior to 2010 sampling period and from the 2010–2019 period. Error bars represent an approximate 68% confidence interval. Note differences in scales of y axes. Abbreviations: RM = Rocky Mountain, GB = Great Basin, and SW = southwestern. See Goeking and Windmuller-Campione for details.

to identify the underlying genetic mechanisms.

In 2016, the Whitebark Pine Ecosystem Foundation and American Forests jointly proposed to the USDA Forest Service leadership the National Whitebark Pine Restoration Plan (NWPRP), a range-wide restoration strategy for whitebark pine in collaboration with federal agencies and tribal jurisdictions. Unlike most previous strategies, which primarily provided treatment types and guidelines, this plan aspired to be primarily geographic, identifying specific areas for restoration across whitebark pine's U.S. range. Plan development relied upon USDA Forest Service regions, National Parks, Bureau of Land Management state field offices, and interested tribal partners to identify 20 to 30% of their whitebark pine as priority (core) areas for restoration, provide information on whitebark pine condition, and identify which restoration actions and treatments were deemed appropriate for use within these priority areas. The plan envisioned that if 20 to 30% of whitebark pine's range were restored with resilient populations, Clark's nutcrackers would facilitate range-wide recovery by transporting seeds with genes for blister rust resistance and climate adaptation beyond the core areas. Full recovery might require a century or several human lifetimes.

The NWPRP as a Model for Other High Five Pines

Although the NWPRP is focused on whitebark pine, Tomback and Sprague (2022) described the process and potential application to developing restoration plans for the other High Five pines (Fig. 2). For each High Five pine, the major steps for Phase I, restoration planning, would be as follows: 1) Develop a range map for the species at a 1 km-scale or finer using all dependable data sources, and identify the federal, state, and tribal jurisdictions involved in management of the pine across its range. 2) Seek expert consensus on appropriate restoration treatments and conservation actions across different stand and health conditions. 3) Within jurisdictions, identify priority areas for restoration (i.e., core areas), using criteria compatible with agency or tribal roles and missions. Identify general health trends and conditions within these core areas. 4) Connect health trends and stand conditions with specific conservation actions and restoration treatments. 5) Construct the restoration plan. Phase II, implementation of the restoration plan for a given High Five species, requires a funding model that encompasses multiple sources, including agency, tribal, and legislative opportunities, as well as partnering with non-profits and the private sector. As restoration treatments are

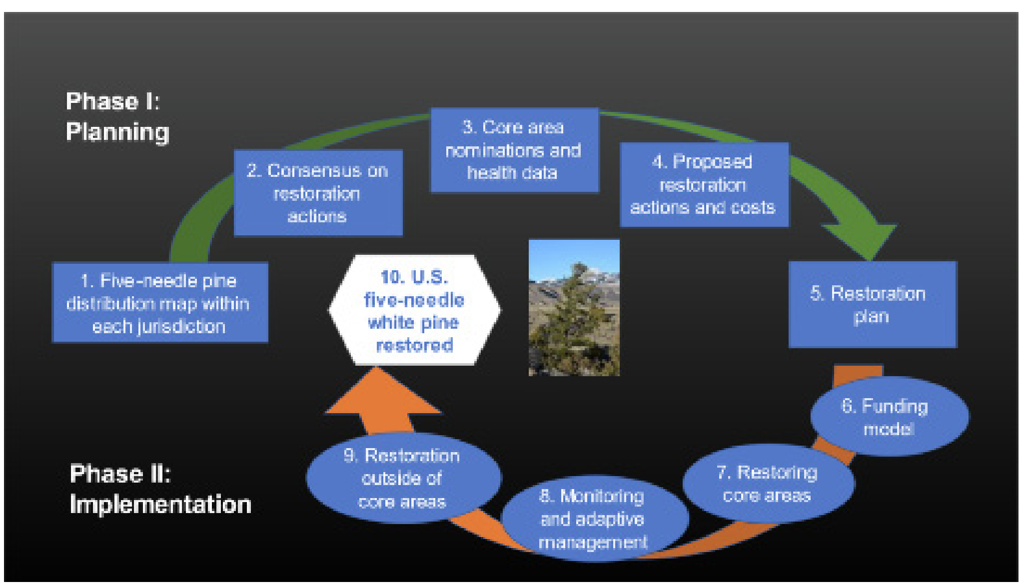

Figure 2. Figure 7 from Tomback and Sprague (2022). This figure illustrates how the major steps in constructing the National Whitebark Pine Restoration Plan can be used to develop a restoration plan for each High Five pine. Phase I of the planning involves assembling the components of the plan. Phase II involves implementation of the plan, including devising a funding strategy. The success of the plan rests on core area restoration and subsequent restoration outside core areas.

designed for given sites within core areas, appropriate monitoring protocols must be devised as well. Monitoring efforts are a high priority to determine whether restoration objectives have been met. If goals are not met or only partly met, an adaptive management strategy may be required, with some trial and error in fine-tuning restoration treatments. If core areas are restored with resilient populations, the target High Five pines may recover across its range over time, perhaps with the support of additional projects.

For the NWPRP, a concerted effort was initially made to identify and examine appropriate restoration actions and treatments. In 2017, during Phase I of the NWPRP, an experts' workshop was conducted that included researchers and resource managers from the U.S. and Canada with experience in various aspects of whitebark pine restoration. The outcome of the workshop, which over time included additional coauthors and input, was a compilation of "Current and recommended management practices" for whitebark pine restoration, published as Tomback et al. (2022). Table 1 presents a synopsis of consensus actions and treatments. Many of these actions and treatments are potentially applicable to the other High Five pines under specific conditions.

Table 1. Modified from Table 2, Tomback and Sprague (2022). Conservation actions and restoration treatments for whitebark pine. See Tomback et al. (2022) for detailed descriptions and recommendations for actions and treatments and Keane et al. (2021) for basic principles and climate change mitigation. WPBR = white pine blister rust. MPB = mountain pine beetles.

1. **Conserve genetic diversity**
    - Seed collections for seed archiving.
2. **Promote genetic resistance to WPBR**
    - Identify seed zones across whitebark pine's range.
    - Select candidate trees (seed trees and plus trees) for WPBR-resistance screening.
    - Screen for genetic resistance to identify trees with usable resistance (elite trees).
    - Identify sufficient numbers of resistant trees to conserve genetic diversity.
    - Develop seed orchards where appropriate for operational seed production.
3. **Grow seedlings to restore populations and build resilience to WPBR and climate change**
    - Collect cones from elite trees and drought-tolerant trees or those from environments considered similar to future climate change scenarios.
    - Optimal goal is to find trees with both WPBR-resistance and drought tolerance.
    - Grow seedlings.
    - Plant seedlings or directly sow seeds, especially in climate change refugia.
4. **Protect trees with known blister rust resistance or high value stands**
    - Protect trees from attack by MPB.
    - Protect trees from fire.
5. **Reduce competition in successionally advanced communities**
    - Apply various silvicultural treatments, depending on conditions and goals.
    - Use prescribed fire as a restoration tool.
    - Manage wildfires.
6. **Implement treatments proactively to build resilience in healthy whitebark pine communities**
7. **Assess whitebark pine health and stand conditions**
    - Implement surveys to assess health status and trends.
    - Monitor stand health and conditions over time.
8. **Develop monitoring plans for restoration treatments and conservation actions**
    - Integrate monitoring into project planning and management.
    - Use monitoring outcomes to adjust treatments for successful restoration and conservation, i.e., adaptive management.

Restoration Planning for the High Five

As described in Schoettle et al. (2022), the six High Five pines are more or less vulnerable to the same threats: white pine blister rust, mountain pine beetle outbreaks, altered fire regimes, and climate change impacts. Species, however, differ in their current range-wide health status, genetic basis and frequency of resistance to blister rust, susceptibility to mountain pine beetles, drought-tolerance, and demographics and thus evolutionary potential. In all cases, restoration treatments will be most effective if targeted to topography and locations where the pines are expected to persist despite climate warming. The following summaries provide approaches to restoration and highlight some concerns for each of the High Five pines.

Whitebark pine has experienced major mortality from a combination of blister rust infection and mountain pine beetle outbreaks. Blister rust, which continues to spread and intensify, has been identified by the U.S. Fish & Wildlife Service as the major threat to whitebark pine. Heritable quantitative (polygenic) resistance to blister rust is distributed at low frequencies throughout many whitebark pine populations, and some trees have levels of resistance that can be deployed for restoration purposes. Sufficient numbers of trees with usable resistance need to be identified for each seed zone, protected from mountain pine beetles and from fire, and monitored for cone production annually. In high mortality regions or in regions with high blister rust infection levels, the major restoration treatment entails constructing viable, blister rust-resilient populations by planting seedlings from rust-resistant parent trees. Plantings should also include seedlings from drought-adapted parent trees and mountain pine beetle-resistant phenotypes, which may also confer some resistance to mountain pine beetle attack. In areas where blister rust has been slow to invade, resilience to blister rust and climate adaptation may be proactively built into populations by utilizing planting opportunities—recent burns or in open stands. Furthermore, in some regions of the northern Rockies and elsewhere, historical fire suppression has resulted in declining whitebark pine in successional communities. The use of prescribed fire and silvicultural techniques may reduce competition from shade-tolerant conifers, favoring whitebark pine survival. This application would be especially important for stands with natural high blister rust resistance or other genetically-based useful attributes.

Limber pine is the next most impacted High Five pine, with high blister rust infection levels and mortality from mountain pine beetle primarily in its central and northern Rocky Mountain distribution. Blister rust has not yet impacted limber pine in the most arid regions of its range. Limber pine is a preferred host for mountain pine beetle and also experiences high levels of dwarf mistletoe (Arceuthobium cyanocarpum) in its southern distribution. Limber pine has been found to have major gene resistance (R gene)—in other words, a single gene confers resistance (low susceptibility) to blister rust— but the gene frequency varies across limber pine's range. Limber pine also possesses quantitative resistance, which is more durable, but at low levels. Concerns are that single-gene resistance can more easily be overcome by a counter-mutation in Cronartium ribicola. The question becomes whether to establish populations using source trees with major gene resistance or to attempt to build quantitative resistance, for example using controlled pollinations in limber pine seed orchards. As in whitebark pine, population resilience to blister rust may be built through planting seedlings with genetic resistance where there are high infection levels and proactively where blister rust levels are still low. Unfortunately, natural seedling establishment, especially after fire, is sporadic and slow, which indicates the need for planting guidelines. Limber pine also exhibits drought resistance traits that can be deployed through planting, once genotypes are identified. Seed dispersal by Clark's nutcrackers can facilitate the movement of both rust-resistance genotypes and climate-adapted genotypes beyond core areas.

Southwestern white pine is infected with white pine blister rust in some regions of its U.S. range, which is restricted to Arizona and New Mexico, and often to high sky island habitats. The species has heritable traits for drought-tolerance, major gene resistance, and modest frequencies of quantitative resistance, which all can be harnessed to provide local resilience to blister rust, mountain pine beetles, and climate change through seedling planting. Planting sites require moister conditions for seedling and tree survival than the other High Five species and may become scarcer with climate warming. One growing concern is the potential loss of entire sky island populations to large, severe wildfires.

Rocky Mountain bristlecone pine is a long-lived species with a disjunct range. Populations are generally healthy, with only one population in southern Colorado infected with white pine blister rust at this time. Shifts in climate or episodic weather conditions over time, or increasing infection in co-occurring limber pine could enable blister rust to spread more widely in this High Five pine. The species shows modest levels of quantitative resistance to blister rust, as well as some heritable drought resistance which could be harnessed through seedling planting to build resilience in populations currently infected by blister rust or proactively in populations not yet impacted. Natural seedling recruitment is low after disturbance in Rocky Mountain bristlecone pine and varies among bristlecone pine stands. Seedling planting guidelines will be important for restoration efforts but require development through trial-and-error experimentation.

Great Basin bristlecone pine is the longest-lived species of the High Five. Its distribution is restricted to high elevations across arid Great Basin ranges, which has provided some protection from blister rust infection, and the pine is not a suitable host for mountain pine beetles. The pine demonstrates some degree of drought-tolerance, but whether it has additional adaptive capacity to climate warming is unknown. To date, populations are not infected with blister rust, but studies show the pine to be susceptible. Initial screenings indicate that populations have quantitative blister rust resistance, which can be used through planting to build resilience in populations proactively. Given that populations are small and isolated, however, they are vulnerable to destruction by fires. Furthermore, natural regeneration is highly episodic and generally sparse, entailing the development of innovative planting techniques in advance of restoration efforts. Planting techniques need to address continued trends in warming and aridity in the Great Basin.

Foxtail pine has a disjunct distribution restricted to California, with the northern population widely infected with blister rust and suffering some mortality from mountain pine beetle. Foxtail pine is highly susceptible to blister rust but has very low frequencies of quantitative resistance, which challenges restoration efforts. In contrast, the pine appears to have inherently high defense levels against mountain pine beetles. Studies indicate genetic variation for drought-tolerance among populations, indicating that genotypes are available to build resilience to climate change. An intensive search for usable genetic resistance in both the northern and southern populations should be launched. Seed orchards for each region using controlled pollinations could be the best vehicle to stack genetic resistance mechanisms in seed production. Restoration strategies will differ between the northern and southern populations, with more urgency to build resilience to blister rust, along with climate adaptation, in the northern population. Demographics in the northern populations indicate good regeneration and reasonable seedling survival. Blister rust, however, has recently been documented in the southern population, which has a different set of demographics. The southern population is comprised primarily of mature trees with sparse regeneration. Planting rust-resistant and climate-adapted seedlings proactively in this population to build resilience is a primary strategy. As indicated for the two bristlecone pines, the development of planting techniques to provide moisture and protection for early seedling growth is an essential step in the restoration process for this southern population.

Restoration Overview for the High Five

In summary, restoration of the High Five pines should focus on priority (core) areas and aspire to develop populations with resistance to blister rust, incorporate climate change adaptation and resilience to mountain pine beetles, and target topography and landscapes for restoration where trees are more likely to persist over time despite warming temperatures. How this is accomplished will vary among the High Five species. Genomic studies to identify genes that confer blister rust resistance, drought-tolerance, and resilience to mountain pine beetle would both speed up and facilitate restoration efforts for all the High Five pines. For those pines which currently have episodic and sparse regeneration, building resilience in populations through seedling planting will require the development of planting techniques to provide moisture and protection in the early years of growth, given projected increasing temperatures and diminishing snowpack. Given that the NWPRP and the U.S. Fish & Wildlife Recovery Plan are in progress, it may be time to begin restoration planning for the other High Five pines.

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Terminal branch dieback along Commissary Ridge in the Bridger-Teton National Forest: Investigating white pine blister rust canker ages and rates of expansion

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White pine blister rust (WPBR) is caused by the non-native fungus, *Cronartium ribicola*, a devastating pathogen of North American five-needle pines. Over the past century and a quarter, this pathogen has proven to be one of the most damaging agents of five-needle white pines (Geils et al. 2010; Schoettle et al. 2022) and is the primary factor in the recent ESA listing of whitebark pine (*Pinus albicaulis*, WBP) as threatened in the USA. Whitebark pine is a high-elevation species of western mountain ecosystems that is highly susceptible to WPBR. Since its detection in the Rocky Mountains of Idaho, Montana, and Wyoming around 1926 (McDonald and Hoff, 2001), WPBR has reduced populations of WBP by as much as 70% in some areas including Glacier National Park (Kovalenko pers. comm.). In other areas to the south, WPBR continues to spread and intensify in WBP. White pine blister rust has not yet been detected in several more isolated WBP populations such as some in the Great Basin and has only recently been confirmed on WBP in the southern Sierra (Dudney et al. 2020).

Significant information gaps remain related to the dynamic host-pathogen-environment interactions and factors that influence WPBR infection events and canker expansion in high-elevation systems. Investigations by Kearns et al. (2009) reported that canker expansion rates in limber pine populations in Colorado and Wyoming were consistent across tree and site factors. Their work determined estimates of years since infection based on canker length combined with an adjustment for latency (time between needle infection and visual symptoms). While this information provides a solid baseline for limber pine, to date we know little about this metric in WBP. Knowledge of

Figure 1. A) Count of bud scars to determine the age of the branch internode at the center of the white pine blister rust canker, estimated to be the point of origin into the branch from the infected needle. B) Sample canker with push pins placed at the edges of the active canker. Measurements in future years will be estimated from these margins.

the distribution of canker ages at locations where WPBR is increasing in severity can characterize the frequency of infection events and pinpoint years with favorable environmental conditions.

During the 2021 annual visit to permanent WBP monitoring plots on Commissary Ridge in the southern reaches of the Bridger Teton National Forest, National Park Service field crews noticed extensive terminal branch dieback in WBP stands located on the top and flank of the ridge. Although WPBR damage has been detected in this area at moderate levels over the past 18 years of monitoring, the sudden, wide-spread branch dieback, approximately 15 to 30 cm in length and retaining red needles, was alarming. A follow-up visit later in the season with an interdisciplinary forest health team confirmed that the majority of observed branch mortality was associated with WPBR. Preliminary canker measurements indicated a potential "wave-year" event evidenced by the high frequency of relatively new cankers (mean canker length 5.8 cm (n=19) with canker centers located on branch internodes ranging from 5 to 12 years old). This discovery offered a unique field setting to investigate canker ages (and year of infection by extrapolation), canker expansion rates, and potential wave year detection in a population of heavily infected and easily accessible WBP. As such, in August of 2022, a pilot study was initiated to assess canker expansion rates, canker ages, and occurrence of wave years, and ultimately, improve methods for field studies and gain a better understanding of disease epidemiology.

Methods

A total of 11 WPBR infected WBP were selected that had active cankers (n=25) on intact, live branches. Four of the sampled trees were on top of Commissary Ridge, and the other seven were located on the eastern flank of the ridge. Measurements taken on sampled branch cankers included: length of canker swelling, length of annual growth increments (based on bud scars) from tip of branch to base of canker, and number of annual growth increments with retained needles (for a subset of cankers). Shoot vigor was estimated as the average annual shoot increment length on the same shoot that the canker length was measured. Needles are the points of infection for *C. ribicola*. Assumptions for measurement calculations include that the latent period is 2 years (time from needle infection to visible symptoms or signs of a canker), and branch cankers expand 2 cm per year in this host-pathogen-environment system. Given these assumptions, the estimated canker age in years is half the total canker length including any swelling or bark discoloration (e.g. 1 cm reflects half of annual expansion of a 2 cm canker) plus 2 years (latency). Annual and monthly vapor pressure deficit (VPD; a proxy for humidity) were calculated for the study site. These data were analyzed to determine if conditions conducive for a wave-year event could be detected.

Results

We saw what appeared to be first- or second-year fruiting cankers on shoot increments ranging in age from 4 to 14 years old, suggesting that needles of all ages can serve as points of infection. On average, needles were retained on shoots for 9 years. Furthermore, we found no relationship between canker length and age of the stem section at the center of the canker (data not shown). Mean branch canker length at the top of Commissary Ridge was 6.4 cm and was 11.6 cm on the lower flank of the ridge. The data suggested that canker expansion varied with shoot vigor (Fig. 2). The mean estimated years since infection was 5.2 and 7.8 years, on the ridge and below, respectively. Trees on the ridge appeared to experience a recent infection wave that did not occur below the ridge (Fig. 3) if the assumptions of our analyses hold true. However, our preliminary explorations of VPD did not detect any obvious episodes with conditions conducive for a wave-year event in the Commissary Ridge area.

Discussion

Preliminary results from data collected in 2022 highlight the need for continued repeat observations over a longer period. Canker expansion rates can be tracked on a yearly basis with simple measurements from marked cankers, while additional data collection will improve assumptions on how canker expansion rates are influenced by shoot vigor, effects of site (tree position on the ridge), and tree age (mature versus younger). Our findings show that WBP needles can be retained for up to nine years at these locations and needles of all ages appear to remain susceptible and serve as in-

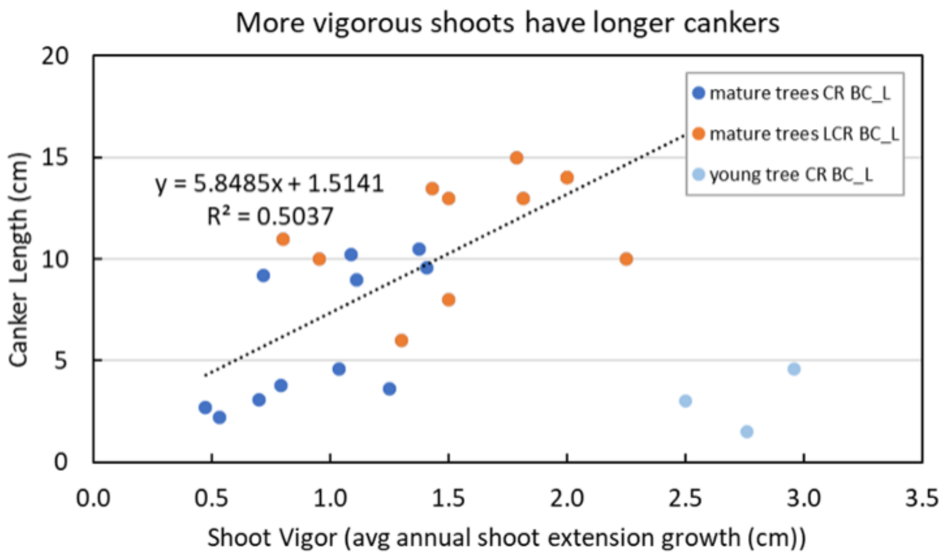

Figure 2. Relationship between shoot growth (vigor) and canker length. Shoot vigor was estimated as the average annual shoot increment length over the past 9-10 years on the same shoot canker length was measured. Cankered shoots from mature whitebark pine trees at Commissary Ridge (dark blue; CR) and the lower flank of Commissary Ridge (orange; LCR) were measured and one young tree (light blue) at Commissary Ridge. Note that shoots of mature trees at the lower site generally grew more per year than those on the Ridge.

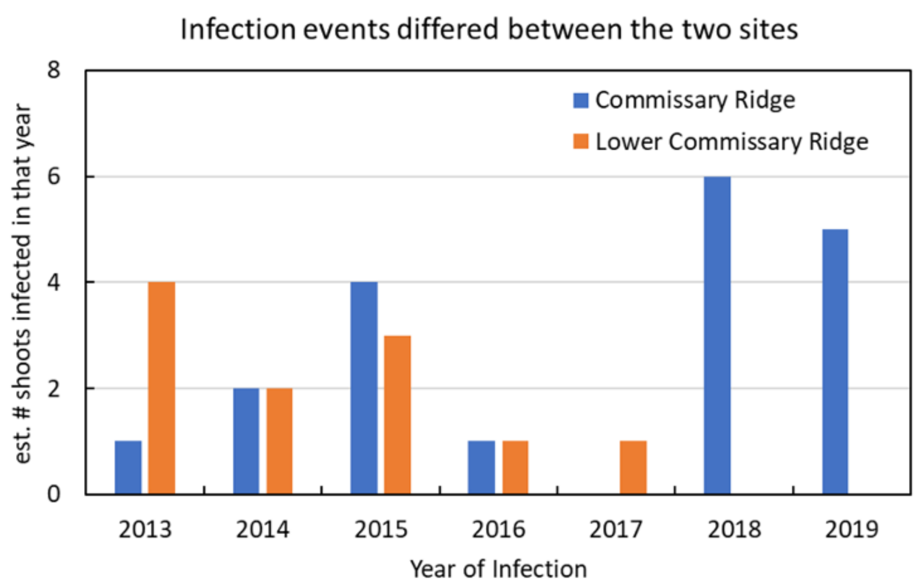

Figure 3. Numbers of white pine blister rust cankers on whitebark pine shoots estimated to have been infected in each year from 2013 to 2019, by tree location (blue indicates trees at the top of Commissary Ridge and orange indicates trees below the ridge.

fection points. Our interpretation of evidence for a wave year event on the ridge is influenced by our assumption of a two-year latent period and an annual expansion rate of two cm per year. Additional data to test these assumptions are warranted and underway. Detection of wave-year events is complicated as environmental conditions favorable for infection may be difficult to tease out by examining means over time and space. Commissary Ridge is positioned to the west and runs parallel to a narrow, mesic valley bottom where morning fog is seasonally common (Shanahan, pers comm). Ribes species are abundant and particularly dense along the small, southerly flowing stream on the east side of the valley. Local drivers of the observed patterns of infection on Commissary Ridge may be related to topographic features, the abundance of host species, and the mesic setting. We will continue to investigate environmental factors at different scales in relation to canker age estimates that suggest years with high frequencies of new infections.

Estimating the year of infection an WBP is complicated because the species routinely retains seven or more needle cohorts per shoot and information on susceptibility by needle age is lacking (Schoettle, pers comm). For example, if only 1-year-old needles could be infected, we could simply equate the age of the cankered stem section with the year of infection;

however, if needles of all ages can be infected, we cannot make that assumption. Hence the need to age cankers and gain more information on the infection probability of needles of different ages, the latent period between infection and visible symptoms, and annual canker growth. Our data suggests that needles of all ages may serve as points of infection; measurement of additional shoots, especially at first signs of canker development, may improve our confidence in this finding. Experimental studies will be needed to better understand mechanisms that determine latency. Annual remeasurement of the pinned cankers will improve our estimates of canker growth rates and possible factors affecting growth. The Commissary Ridge site presents an opportunity to collect data to increase our understanding of canker expansion, infection years, and the epidemiology of this important pathosystem in high elevation 5-needle pines.

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Using drones to support five-needle pine conservation

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Drones, known as Unmanned Aerial Systems (UAS), have proven their worth as powerful tools for forest inventory and monitoring in recent years. UAS have demonstrated surveying advantages and capabilities equal to those of traditional methods in subalpine forests (Burchfield et al. 2020, Lin et al. 2018); however, they have not been widely adopted as a strategy to support five-needle pine conservation. Aerial remote sensing using airplanes and satellites has long been successful in monitoring five-needle pines (Macfarlane et al. 2013, Jouvet and Wilson 2021) but little to no research is available using UAS to target these species (Garms et al. 2020). Identifying transferable UAS strategies for five-needle pine conservation supports the missions of cooperative management initiatives like the National Whitebark Pine Restoration Plan (Tomback and Sprague 2022).

Recent efforts in eastern Oregon's Malheur National Forest demonstrate that UAS operations are feasible for five-needle pine monitoring. We used UAS to explore and inventory five-needle pine habitat in the Strawberry

Figure 1. Katie Nicolato launches a quadcopter to investigate whitebark pine and western white pine on a mountainside blanketed by dense understory vegetation.

Figure 2. John Van Gundy wades through dense ceanothus (Ceanothus sp.) blanketing a fire scar that harbors regenerating whitebark pine and western white pine. UAS provide alternatives to the strenuous and sometimes dangerous field work required in subalpine environments when monitoring five-needle pines.

Mountains during the 2021 and 2022 summer field seasons. The goal was to create a foundational protocol for UAS monitoring of five-needle pines while documenting areas of high management priority on the Malheur National Forest. These operations focused on whitebark pine (*Pinus albicaulis*) and western white pine (Pinus monticola) but methods apply to all five-needle pine species. The Strawberry Range's subalpine ecosystems presented ideal sites for testing UAS surveying capabilities. The diverse and rugged terrain, vegetation composition and variable weather in this region represented global challenges faced when conducting high-elevation field work. Though piloting in these conditions requires an experienced operator, UAS missions conducted on good weather days were successful, enjoyable and allowed surveyors to cover significantly more ground than could be achieved on foot.

Following the success of this work, we recommend integration of UAS operations into management plans focused on five-needle pine protection. Future goals should include repeated field testing and the establishment of a protocol and network for UAS monitoring of five-needle pines.

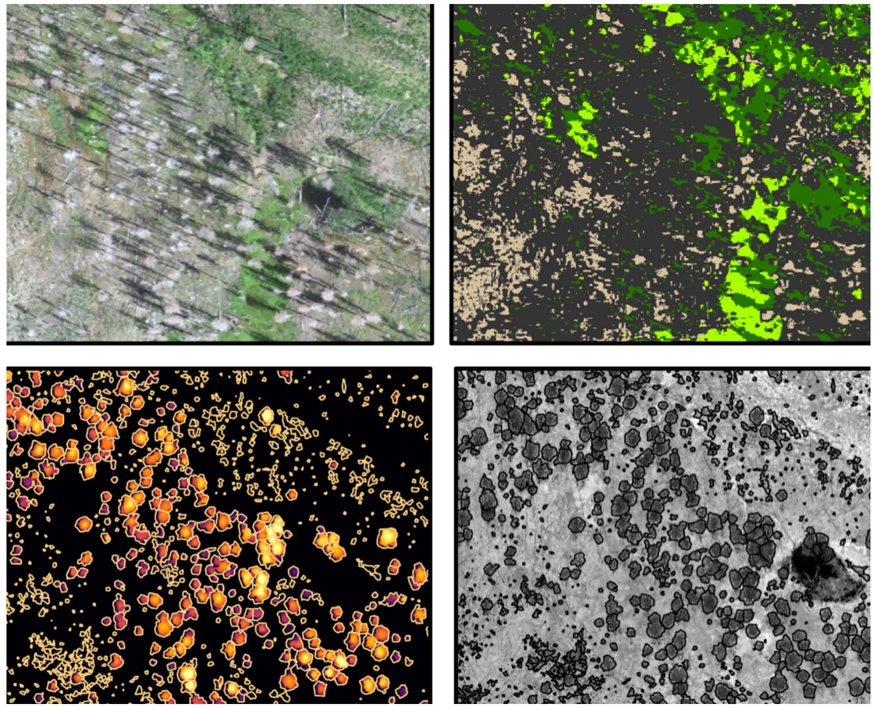

Figure 3. Aerial Light Detection and Ranging (LiDAR) quantifies subalpine forest at the landscape scale when paired with UAS. Shown here are four rasters of the same nadir (overhead) view of a subalpine conifer stand below the summit of Strawberry Mountain. The rasters are examples of aerial LiDAR-derived datasets that can be produced for five-needle pine stands. Top left: 4-band true color orthoimage, top right: landscape classified by snags, live trees, vegetation and ground, bottom left: canopy height model of individual tree crowns, bottom right: LiDAR intensity image of individual tree crowns.

UAS Applications in Five-Needle Pine Conservation

UAS can support diverse management objectives within five-needle pine conservation. We identified seven conservation applications with the potential to benefit from UAS operations:

Stand Exploration

Determining the age, condition and occupancy of five-needle pines across a management area can be difficult on foot due to the rugged terrain commonly found at high-elevation field sites. UAS can save time and reduce risk by

Figure 4. A whitebark pine sapling observed from above. Unique spectral signatures of five-needle pine species can be used to detect regeneration in a stand.

Figure 5. UAS images and video can be used to annually monitor cone production and health in individual trees. This is useful in planning climbing work and cone caging and collecting operations. A visual media database also safeguards trees critical to management objectives and provides training and educational resources about five-needle pines.

capturing data in inaccessible areas requiring strenuous human travel, such as steep and rocky slopes, snow fields and patches of dense understory (Figure 2). UAS also provide higher-resolution imagery than other aerial sources, which makes planning field work and silvicultural actions more efficient.

Forest Inventory and Health Monitoring

UAS can perceive subjects beyond the human eye, both in aerial perspective and on the electromagnetic spectrum. This ability can be exploited to derive individual tree metrics and monitor forest health in subalpine stands (Figure 3). Variables like regeneration (Figure 4) and mortality (Figure 3) are key to change detection when quantifying the effects of reforestation, wildfire, drought, heat, white pine blister rust and mountain pine beetle outbreaks. High-resolution UAS imaging, video, LiDAR and photogrammetry can track important health trends over time in trees and stands.

Cone Monitoring

UAS imagery can produce centimeter-level resolution and accuracy in nadir (overhead) images (Garms et al. 2020) (Figure 5). This is optimal for cone monitoring in trees targeted by genetics research and reforestation goals. Managers can plan climbing, caging and collecting operations based on a database of annual flights estimating cone productivity in priority stands. High-resolution tree top images can be used to quantify cones manually or with an automated classification algorithm.

Visual Media Database

Aerial mages and video are more effective descriptors of forest condition than written observation. It is essential to maintain a visual media database of individual tree and stand health across management areas for scientific and educational purposes (Figure 5). A visual media database can be used to train field crews and project collaborators, educate the public and document coverage of five-needle pines by a management agency. It also provides a steady, up-to-date supply of content for presentations and publications.

Proof of Concept Research

The lack of UAS applications in five-needle pine conservation presents an opportunity for novel research and development. Momentous events like the listing of whitebark pine under the Endangered Species Act in December 2022 direct interest, funding and energy towards innovation in five-needle pine protection. Concurrently, the rapid integration of UAS remote sensing into forestry over the last two decades necessitates novel field testing in subalpine ecosystems. Multispectral imaging, photogrammetry and LiDAR are regularly paired with UAS to measure forest variables at high accuracies (Lin et al. 2018, Burchfield et al. 2020, Garms et al. 2020). New UAS capabilities such as extended flight Beyond Visual Line of Sight (BVLOS) and Simultaneous Localization and Mapping (SLAM) allow these reliable methods to be explored to new limits. UAS introduce landscape-level, noninvasive research solutions equipped for the remoteness and sensitivity of five-needle pine ecosystems.

Science Communication
The growing reputation of UAS in forestry positions them as influential science communication tools for five-needle pine conservation. The excitement and eagerness surrounding this technology can be used to an advantage when developing support for five-needle pine projects. UAS-derived products like high-resolution aerial images, video and 3D models can augment interpretation of five-needle pines to the public and policymakers. Engaging stakeholders in demonstration flights and field missions creates memorable experiences around five-needle pines while exemplifying the latest methods in forest management. Leveraging the widespread fascination and force behind UAS operations in forestry will cultivate stronger connections to five-needle pines through enthusiasm for new protection methods.

Stakeholder Unification
A noticeable shift has occurred in the last decade regarding the integration of UAS operations into forest conservation strategies. It is now common and even expected to encounter agencies, companies and organizations using UAS research and monitoring to support forest management decisions. Though stakeholders are invested in adopting this technology, there remains a desperate need for knowledge, training, and collaboration among those striving to use it. The momentum surrounding their use in forestry means UAS can act as a unifying learning and management goal for those leading five-needle pine conservation. A shared investment in executing UAS operations can lead to resilient relationships between stakeholders.

Conclusion
Constant technological improvements in UAS remote sensing mean better data coverage, quality and availability than ever before. Those managing five-needle pines should consider UAS as a monitoring solution for subalpine forest protection. We recommend expanding the use of UAS to support five-needle pine conservation following successful operations on the Malheur National Forest. Future goals should include repeated field testing and the establishment of a protocol and network for UAS monitoring of five-needle pines. Integration of UAS into management plans would improve landscape-scale protection of these threatened species.

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Here we go again: The mountain pine beetle is killing our remaining old whitebark

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In the last two decades, whitebark pine has experienced severe overstory mortality due to native mountain pine beetle (MPB). The combined effects of MPB, driven by climate change, and damage and mortality from nonnative blister rust and wildfire, were catalysts for its January 2023 listing as threatened under the Endangered Species Act (ESA). Mountain pine beetle caused mortality of whitebark began in the late 1990s and populations reached epidemic levels in the GYE by 2004. Aerial evaluation from the summer of 2009 indicated that 46% of whitebark stands in the Greater Yellowstone Ecosystem (GYE) had suffered complete canopy loss from MPB and 95% of forest stands containing whitebark had measurable MPB activity (McFarlane et al 2013; Figure 1).

In October of 2009, an early season cold snap killed some of the developing brood populations of MPB before they were sufficiently cold-hardened (Logan 2011, Shanahan et al 2016). At the same time, substantial losses were documented in large overstory whitebark that had sustained MPB at epidemic levels over almost a decade. This cold event, combined with the decline of host trees by 75% to 85%, dropped MPB populations back to endemic levels in some areas and significantly reduced epidemics in other regions across the GYE. By 2014, MPB activity was at endemic levels in most locations.

However, in 2019, Forest Health Protection (FHP) aerial surveys and field crews working in whitebark pine habitat detected another notable increase in MPB activity. Results from 2019 imagery showed MPB damage in 100% of whitebark pine stands in the GYE: 18.4% had low mortality; 49.3% had moderate mortality, and 32.3% had severe mortality. In 2020, ground observations of increasing MPB activity were reported in several areas across the GYE, including the Greys River, Salt River Range, the Wind River Range, the Tetons and sites on the Caribou Targhee (Shanahan, Bockino, Beyer, pers. comm.). By 2021, while not directly observed on permanent monitoring transects established by the Interagency Whitebark Pine Monitoring Program, MPB activity and mortality was becoming alarmingly evident to field crews as they navigated to monitoring sites in the southern reaches of the ecosystem (Shanahan, pers comm).

This amplified activity was corroborated by Grand Teton National Park (GTNP) field crews in routine surveys to a subsample of whitebark stands where 333 brood trees were documented in 2021 and 497 in 2022 (Bockino, pers comm; Figure 2). In 2022, a focused survey was conducted to quantify this potentially emerging MPB epidemic in GTNP's whitebark pine stands which encompasses 20% of the whitebark pine population in GTNP. This effort noted 477 brood trees and of the sampled overstory whitebark, 54% were dead from MPB attack. Among the dead sampled, 35% were recently attacked from 2019-2022.

While FHP aerial surveys conducted between 2019 and 2021 generally supported these observations of increased MPB activity, monitoring flights were restricted in 2020 by Covid and in 2021 by poor air quality due to smoky conditions which likely caused an overall underestimation of mapped damage in the GYE (Figure 1).

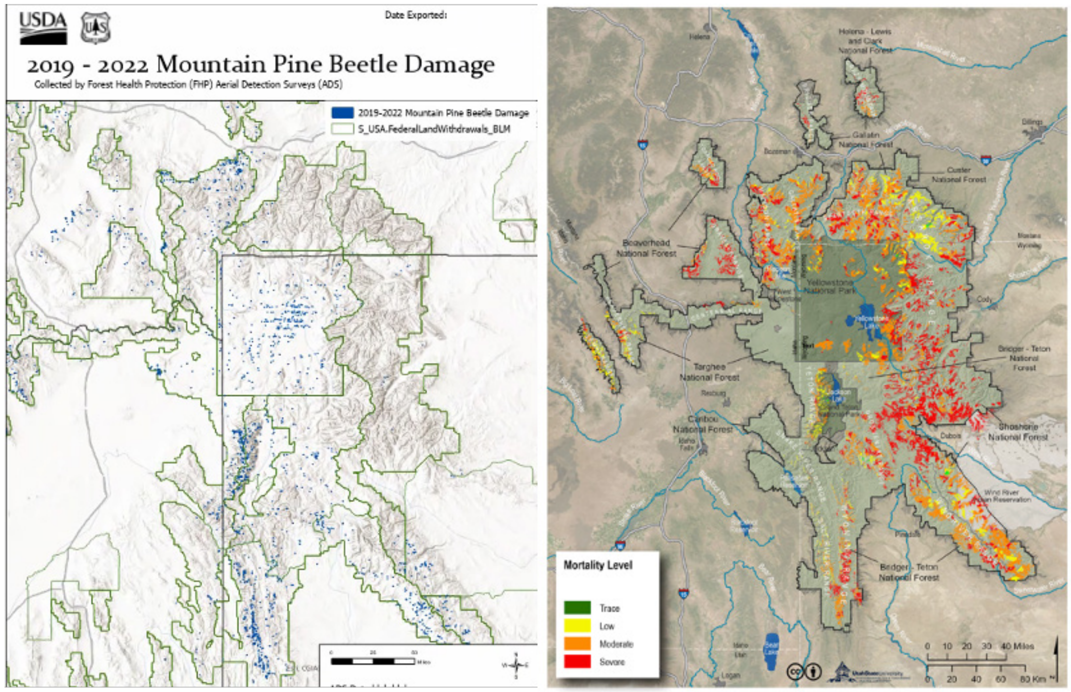

Figure 1. Imagery of mountain pine beetle activity in the Greater Yellowstone Ecosystem from 2019 to 2022 from Forest Health Protection aerial surveys and LAS Data. Each blue dot is a severity weighted polygon that represents up to 99 brood trees per acre. In addition, aerial flights only cover a portion of GYE due to a combination of Covid restrictions and smoky skies that dramatically reduced the areas flow in 2020 and 2021. As such, Figure 1 is likely an underestimation of MPB damage for those corresponding years. The right panel shows estimated mortality by bin classes (low, moderate, severe) from LAS data 2003-2009.

Additionally in 2019, field crews from the Bridger-Teton National Forest and GTNP observed an increase in MPB-related mortality in mature limber pine at lower elevations, particularly in the Gros Ventre Range, Wind River Range, and Wyoming Range. And finally, in 2022, MPB was also recorded in lodgepole pine (Bockino, pers comm).

These data illustrate that an intermediate MPB incipient epidemic is occurring and is trending toward a second epidemic. Since 2019, the annual growth in MPB populations has been sustained, spot infestations are coalescing into larger patches and new infested spots are developing in adjacent stands. This situation and trends are likely the beginning of a second epidemic-level MPB event. Calculations of growing degree days and annual deficit illustrate that conditions favorable for univoltine populations have been building since 2014 (Figure 2).

This is a grave situation for several reasons. First, the loss of any of the few remaining cone bearing whitebark is a significant setback for conservation and restoration. During the 2004-2014 epidemic, extensive healthy stands were reduced to critically low numbers of mature, cone bearing whitebark, but hopefully with a sufficient number of trees remaining to support Clark's nutcracker, its only seed disperser, and whitebark reproduction. However, a second epidemic may result in so few whitebark pine that the delicate and obligate mutualism between the tree and the Clark's Nutcracker could collapse. While several periods of extreme subzero temperatures over consecutive days throughout many regions of the GYE in late 2022 and early 2023 provided hope for potential winter kill of overwintering MPB brood, modeled predictions indicate that the beetles still have about a 50% chance of survival into the next season (Figure 3). This estimation (black line) is similar to periods when beetles remained at epidemic levels for multiple consecutive years.

Real-time management action is urgent. The prioritization of retaining every possible existing seed tree at all costs is unquestionable. Unfortunately, the ESA Listing Rule uses 60-year intervals between outbreaks for scenario evaluations of MPB impact in contrast to what is happening in the GYE. This discrepancy must be addressed with adaptive and timely management based on the on current field observations. Rust resistant, mature seed-producing whitebark remaining on the landscape are extremely valuable and are fundamental to the continued existence of whitebark. If there is to be hope of conservation of whitebark it is paramount that they be protected, from both fire and MPB.

In addition to protecting remaining seed trees, planting rust-resistant seedlings in critical identified habitat is crucial to maintaining reproductive populations of whitebark pine. A combined strategy of planting genetically appropriate seedlings and protecting existing seed trees is key. Both of these strategies must be immediately initiated. There is no time to lose.

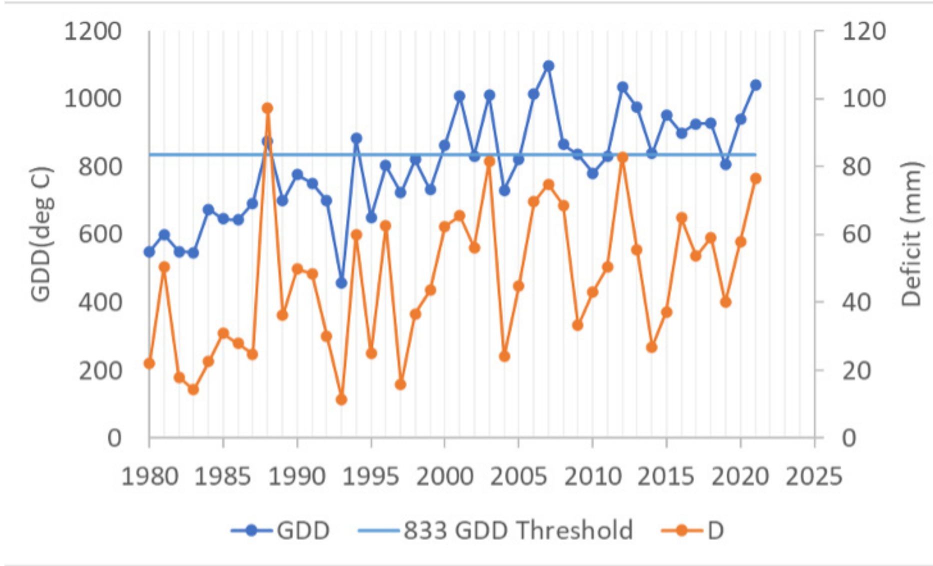

Figure 2. Annual (calendar year) cumulative growing degree days (cumgddc; deg C) and annual deficit (mm) spanning extensive whitebark pine mortality in the early 2000s with its peak in 2009 and the increase in more recent whitebark pine mortality observed from 2019 to 2022. This coincides with a potential build up in MPB populations over several years of ideal conditions for population growth starting in 2014. The blue horizontal line represents the degree day threshold (gdd thresh) for univoltine populations after Carroll et al. (2004). Graph produced by David Thoma, NPS, 2023.

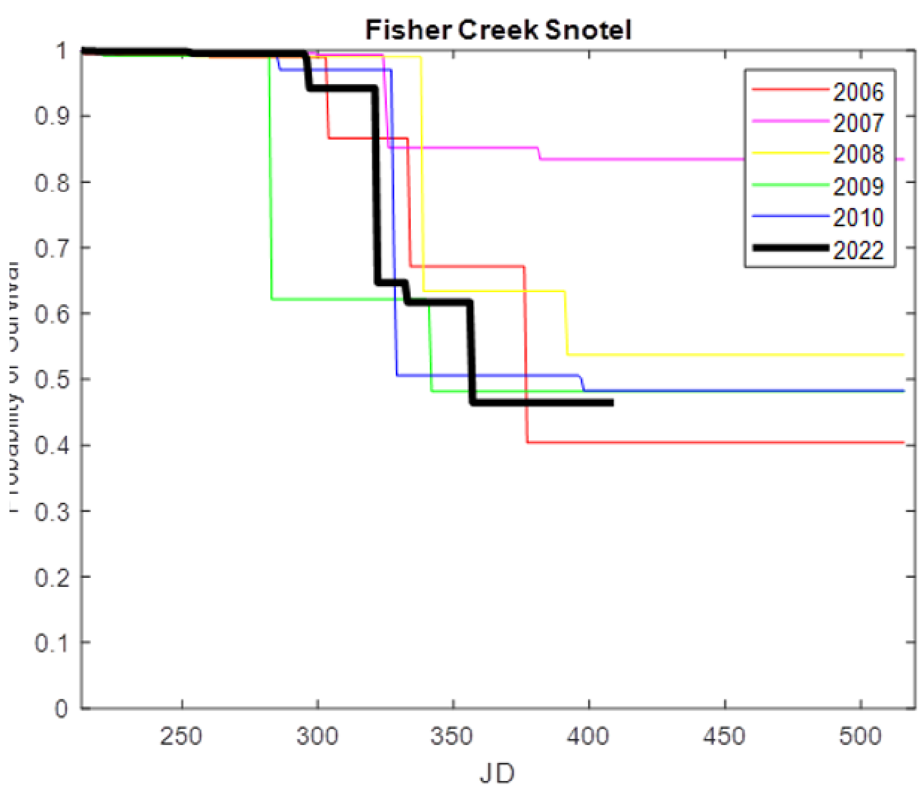

Figure 3. Probability of mountain pine beetle brood survival in consecutive years (JD = Julian Day) 2006 to 2010 and in 2022 from the Fisher Creek Snotel station. Graph produced by Barbara Bentz, USFS-RMRS, 2023.

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Can seedling protectors improve the odds for whitebark pine reforestation?

Elizabeth Barnes
US Forest Service, Payette National Forest

In October 2022, tiny whitebark pine seedlings – most less than 4 inches tall – were planted into the fire-blackened soils on Cuddy Mountain. Two years ago, the Woodhead fire raced across this mountain peak on the Payette National Forest in west-central Idaho, exposing bare mineral soils and creating ripe conditions for forest regeneration. While the bulky, crumbly pinecones of the whitebark pine are not serotinous (fire-dependent), fire may still benefit whitebark pine regeneration. In a 2015 Fire Ecology Article by Judy Perkins, whitebark seedlings had better germination, growth, and survival in recent burn areas than in unburned areas. Higher concentration of some nutrients in soil and more light availability might be the reason for improving seedling outcomes in burn areas (Perkins 2015).

On Cuddy Mountain, we can't rely on wildfire alone to prepare for our seedlings' success. Conditions here are drier than typical whitebark habitat, and weather patterns can be erratic and influenced heavily by the steep gorges of the abutting Snake River Canyon. After a previous attempt to plant whitebark on the Payette NF (on Brundage Mountain, McCall Ranger District 2018), estimated seedling survival in the 3rd year was a dismal 7%. With that loss in mind, we set our sights on trying new methods to improve whitebark seedling survival and started the Cuddy Mountain Whitebark Seedling Survival Study. The study enrolls the 5,800 whitebark pine seedlings planted on Cuddy Mountain in 2022 to test the effect of two seedling protection methods on growth and survival (Photo 1).

The Cuddy Mountain seedlings were assigned to three groups to compare the effectiveness of seedling protection. The first

Photo 1. Three experimental treatments to improve planted whitebark pine seedling survival. LEFT: Whitebark seedling with no treatment; CENTER: Zipset seedling guard; and RIGHT: Coco weed guard mulch mat. All treatments are 100% biodegradable. During the plant, our bilingual planting crew came up with nicknames for the seedling protectors – "fajitas" and "casitas". Can you guess which one is which? Photos: Elizabeth Barnes, WZ Forester, Payette NF

group was planted with no special treatment as a study control (n=2,890). The second group were planted with seedlings guards (1,050) made of decomposable cardstock. The third group were planted with coco-fiber mulch mats (480). Each group was replicated 3 times for a total of 9 planting areas. A fourth group was created spontaneously, when contract planters from Imperial Forestry along with Forest Service personnel in the field decided to go rogue and try using both a guard and mat together (n=100). All seedlings were planted in areas that were forested pre-fire, in shaded microsites next to stumps or snags. (Photo 2).

Photo 2. Forestry Technicians from Imperial Forestry plant whitebark on Cuddy Mountain with seedling guards in hopes of improving survival.

After planting, three permanent monitoring plots were installed in each of the 9 planting units for a total of 27 plots. Baseline data was recorded immediately post-planting. We measured baseline seedling height, diameter, location, shade type and size, seedling condition, and condition of the mat or guard. These metrics will allow us to monitor and compare seedling growth and survival, as well as the durability of the mats and guards over time. We will return to the study plots as soon as the roads are passable in spring 2023 to see how the seedlings and protectors weathered their first winter and share the initial results. After that, plots will be monitored once annually for 5 years. The study hypothesis is that seedling growth and survival will be improved with use of a mulch mat or guard.

Photo 3. (Left) Certified tree climber Keith Wilson, Boise National Forest, stands under a whitebark pine tree where he installed cone covers to protect the seed from birds and squirells until it can be collected later that summer. (Right) a protective cone cover shelters a cone cluster hight atop a whitebark pine tree.

The seedling guards and mulch mats are relatively inexpensive, and both have a low environmental impact. We searched high and low to find a seedling guard not made of high-density hydrocarbon to avoid polluting the landscape with windblown plastic guards. The seedling guards we found are the Zipset TM 2” x 6” lightweight punched Plant Bands at a cost of 6 cents per band. The plant bands are available in a variety of sizes, punched or unpunched, and light or heavy weight construction. The lightweight construction is advertised to maintain structural integrity for 9-12 months. We installed the plant bands with 2 bamboo stakes pushed 2" into the ground. The 6" size topped most seedlings by 1" so the punched holes are critical to filtering light through. The mulch mats, a product typically used in 1-gallon nursery pots to reduce weeds and water loss, are also 100% decomposable. We purchased the Coco Weed Guard 29 cm diameter for about 52 cents each. We secured the mats with 2 bamboo stakes pressed 2" into the ground.

The study on Cuddy Mountain is made possible by years of planning and preparing to plant whitebark pine on the forest. Whitebark pine needs to be sown 2 years before out-planting to achieve the necessary height growth. To ensure whitebark seed for the future, we contracted tree climbers in early spring 2021 and 2022 to collect whitebark cones from a population on forest identified by genetic testing to be highly resistant to the invasive blister rust fungus, Cronartium ribicola (Photo 3). A small group of foresters and forestry technicians certified in tree climbing to assist in checking cone maturity prior to cone caging and collection. In late summer 2021 contractors collected 7 bushels (~1750 cones) of whitebark cone that was sent to the nursery for processing and seed extraction. Some of these seeds went to our seed inventory, others were sown that winter for our next planting in Fall 2023.

Deciding to plant whitebark on Cuddy Mountain requires careful consideration. Each whitebark seed is a precious resource and this location is at the edge of habitat suitability and today supports only a small number of staggered whitebark individuals. Furthermore, the planting area is the confluence of three Payette NF range allotments and is frequently traversed by small herds of roaming cattle. By planting whitebark there, we walk a narrow path to ensure any potential impacts to the seedlings are monitored, while working closely with range managers to mitigate negative perceptions of panting this endangered tree on working lands. In short, our study may also serve as a case study for whitebark pine restoration in active cattle allotments. The success – or failure – of our seedling protectors must also be evaluated in this context.

Planting seedlings has been identified as one of the key actions towards supporting recovery of the recently listed whitebark pine tree. We must find ways to improve seedlings survival rates if we are to meet this challenge. Ongoing planting projects are the perfect opportunity to test new and creative methods. Assessing the effect of various treatments can be easily incorporated into routine project monitoring with little additional effort. Reforesting whitebark in burn areas has the advantage of having good site preparation, and wildfires in general have the added benefit of providing legal and social impetus for forest managers to plant more whitebark. We would love to hear what new innovative methods you are trying on your forests and to compare our nutcracker notes together.

A legacy of dedication

Nancy Bockino, Research Associate & Whitebark Conservation Program Lead
Northern Rockies Conservation Cooperative

"The true meaning of life is to plant a tree, under whose shade you do not expect to sit."
– Nelson Henderson

As a child of a science teacher and naturalist my training began in the 1970s. Now as a field ecologist for the past 28 years I have had the honor of contributing to the conservation of our precious natural resources and to the knowledge that promotes the use of good science in management decisions.

Reflecting on the past 22 years of my work on Whitebark Conservation in the Greater Yellowstone Ecosystem it is clear that this legacy, a labor of love, is built of passion, commitment and connection. The whitebark pine, resilient characters and my dear friends are strong and grounded, old and wise and in desperate need of our help. Only continued dedication and timely action will save them from extinction.

Conserving whitebark pine is crucial to the resilience and health of the ecosystems of the Rocky Mountains, water conservation in the West and the stability of our wild places. I will have been successful if long from now future generations can meet and fall in love with the whitebark pine, drink the water they protect and rest in their shelter on a cold windy winter adventure or enjoy the shade from their branches on a hot summer hike.

This legacy is built on the dedication and hard work of my amazing team of Whitebark Warriors. This team has changed over the past 22 years; each member has left their own mark on the alpine forest, working with fervor to protect something more precious than we can even comprehend. Our team is employed by the Northern Rockies Conservation Cooperative in partnership with Grand Teton National Park and the Caribou Targhee National Forest, working across the entire Greater Yellowstone Ecosystem, wherever our energy and dedication is needed.

One of the most unusual and important tasks our team performs is the collection of precious whitebark pine seeds, to be used for replanting.

Like any day of whitebark field work, a day of cone work begins days before, understanding the weather pattern and checking sites for cones. For cone work not only do we need the weather to be dry and lightning free, we also need winds less than 25 mph. And even calmer than that is

And, like every day of whitebark field work, we must get an "alpine start". We go to bed as early as we can and awake at 3-4 am to provide time to get to the far away whitebark stands. Often we are racing afternoon wind and thunderstorms and snow that will become too soft for traveling on.

We have packed the night before, using a checklist as to not forget one of the many items that fill our large and heavy packs. We enjoy some coffee in the wee hours of the morning and begin our journey to the top of a whitebark. We hike many miles in the morning light as quickly as we can.

Whitebark cones must be covered with wire mesh in June and July and left to finish growing until September. We call this first step caging. If we do not cage the cones, the Clark's Nut-cracker will take each and every seed and cache the far and wide, as that is his very im-portant job.

We only cage a few cones in each tree as to leave some for the Clark's. This amount is based on the research of a brilliant scientist who has studied the whitebark her entire career. It is also based on the ethic we follow - to listen carefully to our Ancient Alpine Teachers, the trees and the busy alpine forest engineer, the Clark's.

Whitebark cones grow at the very very top of the tree. And the very very top of a whitebark tree doesn't have a main trunk, rather many small branches. Each team member is a certified, well-trained tree climber. I have 18 years of tree climbing experience, several other members have 7 years, and 2 members will learn this coming season. However, regardless of experi-ence and training, the task of gathering the cones is always a challenge and requires bravery, strength and composure.

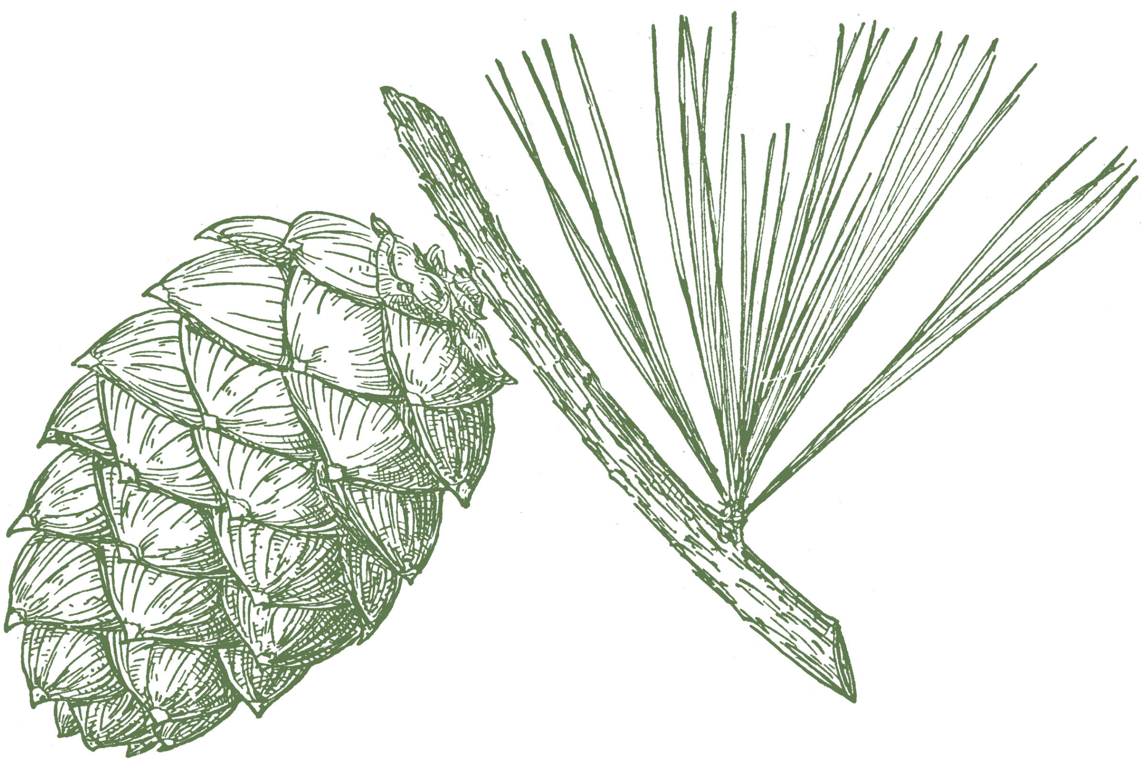
Every day before the team begins climbing each tree we perform a standardized inspection and rating of the tree hazard, inspect our equipment, review our plan, communication and safety system.

Getting into the tree requires climbing a rope that we install from the ground. This seemingly "magic trick" technique utilizes specialized equipment and allows us to safely and quickly as-cend the tree without damaging the branches.

In the tree, we lovingly call "the green room", it is hard to move about with sticky sap, with branches catching your clothing, ropes and untying your shoe laces. We use multiple safety lines as we proceed to the top of the tree. In very large trees, two team members work to-gether to get the cages to the top.

Covered in sap and tree bark dust we rappel back to the ground and begin the process again in another tree. But not before a moment of joy and gratefulness for the chance to spend time in the most unusual and beautiful place. High above the ground in the crown of the most magnificent Ancient Alpine Teacher.

This whitebark pine conservation work, in addition to mountain guiding, has defined my life. It is my path, commitment and an honor. I will continue to speak for the ancient trees that grace the Earth in her steepest places, as long as they need me.



New and exciting research papers

Bob Keane, Editor *Nutcracker Notes*

This is a column to get everyone caught up on the latest and greatest papers to be published over the last six months. In this issue, we highlight some interesting studies that were published thus far in 2022 - 2023.

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MEMBER PROFILE

John Van Gundy

Whitebark Pine Citizen Scientist & Philanthropist

John Van Gundy leads a full and fascinating life as a conservationist, citizen scientist and philanthropist. On any given day, you may find him rowing the Arkansas River to raise money for charity, bushwhacking through the Ecuadorian rain forest, or scouring the remote mountain sides of Oregon in search of whitebark pine. Van Gundy also sponsors a WPEF student research grant focused on whitebark pine dynamics under climate change. We reached out to learn more about his background and interest in funding research on high-five pines.

John in the rain forest of Ecuador where he works on reforestation projects.

Early Roots As A Conservationist

Although born and raised in the cornhusker state, John Van Gundy references a homegrown reverence for forests. "I'm a native Nebraskan, and Nebraskans love trees," he says. In fact, the first Arbor Day celebration was held in Nebraska in 1872 and the state is home to the Nebraska National Forest at Halsey, which is the largest human-made forest in the U.S.

For Van Gundy, his appreciation for forestry was further cultivated during boy scout troop campouts on a large tree farm outside of Lincoln. He went on to study science and English as an undergraduate at the University of Nebraska, followed by graduate work at the University of Iowa. He also worked a summer stint in the Strawberry Mountains on the Malheur National Forest in eastern Oregon between semesters in college.

A Philanthropist By Nature

After schooling, Van Gundy combined his interest in science and writing into a nonprofit professional career with an exploration geophysics society headquartered in Oklahoma. He also immersed himself in the Tulsa philanthropic scene in support of community projects with organizations such as Catholic Charities and Downtown Lions Club. In 2007, Van Gundy had the opportunity to found the Arajuno Foundation, a nonprofit that funds projects in the Upper Amazon River Basin of Ecuador in collaboration with indigenous Kichwa communities, and serves as board president. Together, they are reforesting the local rain forest to provide important food sources, stabilize erosion along the river bank, and protect breeding habitat for the vulnerable yellow-spotted Amazon River turtle.

Work As A Whitebark Pine Citizen Scientist

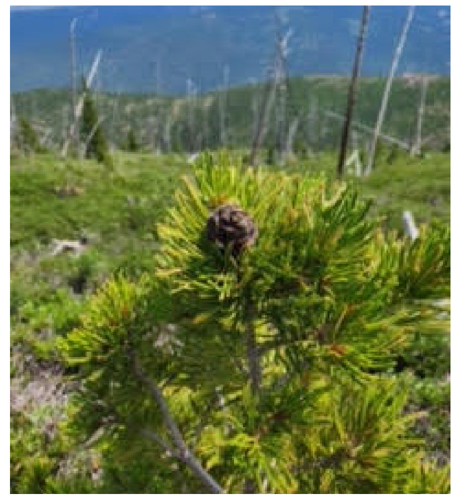
Van Gundy has since returned to the summer of his youth and currently lives one mile from the northern boundary of the Strawberry Mountain Wilderness. It was here that he further became interested in the plight of whitebark pine when working with U.S. Forest Service entomologists on a verbenone research study to protect the tree from mountain pine beetle attacks.

Now semi-retired, he has continued surveying whitebark pine in the area as an independent citizen scientist with team members Mike Bohannon, botanist on the Malheur National Forest, and Katie Nicolato, UAV geospatial analyst for the Davey Resource Group. The group conducts ground and drone-assisted surveys to map populations and monitor post-fire regeneration.

Climate Change At Forefront Of Research Questions

Van Gundy's interest in studying whitebark pine is steeped in poetic explanation. "Whitebark pine is a sublime tree species, almost geologic in lifetime. When you extract a core from a dead whitebark pine, it's tantamount to opening a book on centuries of weather and fire history." He continues, "Time telescopes in a tree. I would think it's a dendrochronologist's dream." He emphasizes that climate change should be at the forefront of any scientific research questions. "Climate change takes precedence over all other worldly considerations — trees and forests being just one of many measurements of the impact on the future," he comments. For example, the team discovered very young, cone-producing whitebark in a post-burn area last season. He hypothesizes this may be due to a climate change-induced epigenetic effect with heat and drought causing premature cone production.

Van Gundy has funded five years of whitebark pine student research grants (i.e., five needles, five years) focused on climate change, which has supported several projects examining the role of carbon allocation in response to stress conditions. You can read more about Van Gundy and his team's research in this issue of *Nutcracker Notes*, along with past issues #41 and #43. Team member Katie Nicolato also presented a WPEF webinar on their work in May 2023.



ELECTIONS

2023 Election News

Bob Keane, Associate Director & Chair of Nominations

It may be an off year for presidential elections, but WPEF has a major election every year. Each year we elect new board members and officers to infuse new ideas and energy into the organization. As is often the case, most of our elections rarely have a full slate of people on the ballot. Instead, we often need to plead with existing board members to run for another term because no one submitted a nomination for their board position. Such may be the case for this year's elections – no nominations have been submitted as yet. So, if you know of anyone who wants to help restore a valuable species and work with some of the greatest people on earth, please nominate them or yourself using the nomination form in this issue.

This is a huge election year for WPEF. There are three officer terms that are expiring: (1) Associate Director (Bob Keane), (2) Treasurer (Glenda Scott), and (3) Membership Coordinator (Michael Murray). None of these are at the end of their three-term limit so they could still be running for another term. In fact, Glenda and I have decided to run for one more term.

In addition, there was a resignation from Board Member #3 (Cliff Bara), and the board appointed

Donna Kridelbaugh to serve Cliff's remaining term. This board position will be open as Donna has decided not to run. The other two board positions that are open are BOD #7 (Danielle Ulrich) and Cara Nelson (BOD #8). Danielle has decided NOT to run for a new term, so we will need to elect someone new to that position.

If you are interested in running or in nominating a person for Office or Board position, please let me know (bob.keane@whitebark-found.org). Again, nomination forms for 2023 year's elections are available in this issue of *Nutcracker Notes* and at the Foundation's website (www.whitebarkfound.org). A comprehensive list of responsibilities for each of the positions is detailed in our Executive Handbook that I can provide upon request. Nominations close on **May 30, 2023**. Final ballots will be sent electronically to each member in good standing, unless a mail ballot is requested, sometime in June 2023. Members will then vote on the three positions by the end of June 2023. Those elected will start their terms after the fall Annual Conference.

It is not necessary to be a whitebark pine expert to become a WPEF board member. We are seeking nominees with diverse perspectives and experiences to fill these positions. Your active participation is critical to keeping the Foundation relevant to the general membership. If you have any questions about any of the positions or the nomination process, please contact me at bob.keane@whitebarkfound.org

CONFERENCE

2023 WPEF Conference

Pines & People: Human Impacts on Five-Needle Pine

The time has come to register for the annual Whitebark Pine Science and Management Conference. This year's theme: *Pines & People: Human Impacts on Five-Needle Pine.*

Occurring this year on the 12th & 13th October in Revelstoke, BC with two optional field trips. A pre-conference trip on Oct 11th to tour the Kalamalka Research Center & seedling inoculation facility in Vernon, BC; and a post-conference trip on the 14th to visit 5-needle pine stands near Golden, BC.

Co-hosted by Parks Canada, this year's theme covers the myriad ways that the activities of people intersect with the welfare of five-needle pine. Over the two-day conference, there will be current technical talks, a public talk, a poster session, silent auction, networking events, and more. This conference has something for everyone...

Are you:

- **A Skier**? Discover how you can help conserve the slopes you love
- **A Student**? Submit a poster application, volunteer, &/or learn the latest
- **A Member**? See your support of whitebark and limber recovery
- **A Business**? Sponsorship opportunities are available
- **A Researcher**? We are accepting abstracts for presentations until 21 June
- **An Enthusiast**? Come learn how you can contribute to the cause
- **A Land Manager**? Connect with the experts on best management practices

Early Bird Registration is open until June 30th. Access conference details and registration information. We've also attached a conference poster that you could print or distribute to your interested contacts.

We can't wait to see you! Don't hesitate to contact us with your questions or speaker/poster submissions.

Whitebark Pine Ecosystem Foundation of Canada

WPEF student research grants awarded for 2023

There were four proposals that were reviewed by the Evaluations Committee, composed of former board members Bryan Donner, Cyndi Smith, and Kathy Tonnessen, and Nutcracker Notes *editor and associate director Bob Keane. We are pleased to announce that LOU DULOISY, a PhD student with Dr. Danielle Ulrich of the Faculty of Biological Sciences at Montana State University, was chosen as this year's WPEF grant recipient. We are also pleased to announce the 2023 recipient of the John Van Gundy student scholarship, administered by the WPEF is JESSICA HARRIS, another MS student with Dr. Danielle Ulrich of the Faculty of Biological Sciences at Montana State University. Their proposals are summarized below, and the literature cited is available on request.*

Evaluating physiological differences of closely related high-elevation five needle pines: Pinus albicaulis and Pinus flexilis

Lou Duloisy

Background and Objectives

Whitebark pine (*Pinus albicaulis*: WBP), is considered a keystone and foundational species in the Greater Yellowstone Ecosystem (GYE) and was recently listed as a threatened species under the Endangered Species Act. WBP thrives at the subalpine tree line and provides vital protection for other species, due to its tolerance of cold, dry, windy conditions. The large and nutritious seeds of WBP supply valuable food resources for wildlife, including the Clark's Nutcracker (*Nucifraga columbiana*) and Grizzly Bear (*Ursus arctos horribilis*) (Tomback et al. 2001). Previous research found that Grizzly Bear survival in the GYE is strongly linked to seed availability and production (Felicetti et al. 2003). WBP also provides vital watershed protection by regulating snowmelt runoff and soil erosion (Keen et al. 2020).

Given their ecosystem services, WBP has a disproportionally large impact on ecosystem health. Limber pine (*Pinus flexilis*: LP), an early successional species, is tolerant of warm and dry conditions and generally occupies the lower tree line ecosystem. Although LP is a drought tolerant and shade intolerant species, it forms open canopy stands unlike the tree islands formed by WBP (Letts et al. 2009, Webster and Johnson, 2000). Despite these differences, WBP and LP can occupy similar geographic ranges in the northern Rocky Mountains. Current research predicts climate change will continue to affect both species (Hansen et al. 2021), though the underlying physiological mechanism are not fully understood. WBP and LP differ by seed cone; identification of non-cone bearing trees is difficult and the lack of effective techniques hinders research in areas where both species are present (Alongi et al. 2019, Baumeister and Callaway 2006). Current species distribution models assume that WBP does not inhabit the warm and dry conditions at the lower tree line where LP is present. However, future climate scenarios fail to include juvenile trees, and previous research shows that juvenile WBP are able to regenerate in warmer and drier environments than their adult counterparts (Buermeyer et al. 2016).

The frequency, intensity, and duration of severe droughts and heat waves are projected to increase, affecting tree growth and survival, and increasing tree mortality

(Allen et al. 2010, 2015). WBP has experienced decline due to the changing climate, mountain pine beetle (Dendroctonus ponderosae), blister rust (Cronartium ribicola), and fire exclusion (Brar et al. 2015, Macfarlane et al. 2013). As a result of the challenges associated with WBP and LP identification, limited research has been conducted examining the physiology of both species. This lack of research limits our ability to conserve and manage these forest ecosystems, considering changing climate. Understanding how physiological mechanisms contribute to species' range limits is important for assessing WBP and LP responses to a changing environment. Inherently, increasing our knowledge of the physiological mechanisms of both WBP and LP is critical to management of ecologically sustainable forests.

Given the importance of conserving forests, specifically WBP, a multi-proxy research approach is needed. To quantify physiological mechanisms in WBP and LP, we plan to measure gas exchange and water relations (photosynthesis, respiration, and transpiration) with in situ methods. However, in situ physiological measurements of plant responses to the environment cannot be applied retrospectively (Siegwolf et al. 2022). As such, tree-ring carbon stable isotopes (δ13C) are crucial for understanding tree physiological responses over temporal and spatial scales (Cernusak and Ubierna, 2022). Additionally, a critical factor in understanding tree physiology is assessing the storage and allocation of carbon, by measuring non-structural carbohydrates (NSCs) in addition to gas exchange and δ13C (Sevanto et al. 2014, Cho et al. 2022). The objective of our study is to better understand WBP and LP physiology over a temporal scale to address the following questions: 1) Do seasonal patterns of leaf-level photosynthesis, respiration, and transpiration differ between WBP and LP? 2) Do tree-ring stable isotopes (δ13C) differ between WBP and LP? 3) Do seasonal patterns of NSCs differ between WBP and LP?

Study Plans

To conduct this research, we will be visiting three sites located in the GYE. Our sites are previously established, with genetically identified WBP and LP (Alongi et al. 2019, Hansen et al. 2021). Each site will be visited once monthly to gather seasonal physiology data. At each site, we will measure photosynthetic rate and gas exchange (stomatal conductance) using a portable photosynthesis system from LICOR Biosciences (LI-6800) and water potential using a portable pressure chamber (PMS). Additionally, we will collect samples from all genetically identified trees, and all tissues (needles, branches, stems and roots) to measure NSC content throughout the duration of the study. We will measure both total NSC content, as well as patterns of allocation to different tissues. Once throughout the study, we will collect tree cores. Two 12-mm cores (20 cm depth) will be taken to quantify recent tree-ring radial growth and tree-ring δ13C. These cores will be cross-dated, and we will measure tree ring widths. Then, the last 50 years/rings of growth will be separated from each tree core using a razor blade. From each ring, alpha-cellulose will be isolated using a standard bleaching protocol (Rinne et al. 2005). The alpha-cellulose will be weighed and packaged in tin cups at Montana State University and analyzed for δ13C, using an Isotope Ratio Mass.

Measures of Success

This study will improve our understanding of seasonal and long-term physiology of two cohabitating species, WBP and LP. The data collected will allow scientists and managers to establish a stronger understanding of WBP and LP physiology and prioritizes adaptive management in our changing climate. Due to WBP being a keystone and foundational species, management of WBP and LP forests is crucial for preserving valuable food resources, watershed protection, and species protection.

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Assessing within species variation of seedling growth and physiological traits in Whitebark Pine (Pinus albicaulis) across climatic gradients

Jessica Harris

Background, Objectives, and Justification

Over recent decades, Whitebark Pine (*Pinus albicaulis*: WBP), has seen radical population declines due to white pine blister rust (*Cronartium ribicola*: WPBR), mountain pine beetle (*Dendroctonus ponderosae*: MPB), understory habitat encroachment, and climate change-induced drought. While WPBR is the leading threat to WBP, higher global temperatures will increase the frequency, duration, and severity of drought (Allen et al. 2010, Chmura et al. 2011, Cartwright et al. 2022). To compound upon this, drought is also a precursor to WBPR infection and MPB infestation (Tomback et al. 2022).

These threats have resulted in WBP being listed as "threatened" via the US Endangered Species Act in 2021 (Tomback et al, 2022). The loss of WBP has serious ecological repercussions for high-elevation forests throughout western North America. WBP is a long-lived and slow-growing species that is a keystone and foundational species. WBP seedlings are often the first tree species to establish in the subalpine tree line ecosystem despite the nutrient-poor soils, short growing seasons, and extremely cold, windy, and bright conditions common to this environment (Tomback et al. 2001). Accordingly, WBP seeds are a vital food source for endangered species such as Grizzly Bear and Clark's Nutcracker. WBP also creates a suitable microclimate for the regeneration of younger and more shade-tolerant plant species (McLane and Aitken 2012).

To restore and conserve WBP, USFS restoration efforts have focused on outplanting rust-resistant seedlings. These efforts require research that identifies which families have the greatest chance of successfully surviving in those areas. One major factor that determines which families should be outplanted include their capacity to overcome the bottleneck of seedling establishment. This capacity is demonstrated via traits such as seedling growth, biomass, phenology, and carbohydrate traits. During early life stages (< 2 years), WBP is especially vulnerable to mortality due to both abiotic and biotic stressors. Importantly, climate-induced drought has been identified as potentially the greatest limiting factor for other high-elevation pine seedlings with drought resulting in shorter individuals, lower leaf area, altered germination and establishment rates, and altered non-structural carbohydrate dynamics (Broderson et al. 2019, Smithers and North 2020).

To ensure that outplanted seedlings can survive into reproductively mature adults, identifying which families have the highest rates of seedling establishment (due to optimal drought resistance and response) is imperative for successful cost- and time-effective restoration efforts.

My research fills this knowledge gap by identifying the intraspecific (within species) variation in seedling growth (leaf area, root biomass, etc.), phenology (emergence, establishment, survival rates), and drought resistance (non-structural carbohydrates: NSCs) within 50 WBP families. These WBP families originated from locations spanning the east-west precipitation gradient of the Cascades Mts from southeastern Oregon, northern Washington, and the Coastal and Northern Rocky Mountains in British Columbia. Objectives of this study are to: 1) identify which families have the highest rate of establishment, 2) investigate whether successful establishment rates are correlated with specific USFS seed zones or British Columbia Forest Service (BCFS) locations and 3) determine a timeframe for how many months were required for successful families to reach the emergence and establishment stages, 4) identify correlations between establishment and survival with growth, phenology, and drought resistance traits, and 5) determine if precipitation and temperature are correlated with family-specific traits.

Study Plan and Methods
To accomplish these objectives, a greenhouse common garden experiment was implemented and seed from each of the 50 families (seed donated by USFS and the BCFS) was grown in the same controlled environment at MSU's Plant Growth Center. Methods included seedling growth (non-destructive and destructive measurements), phenology (seed counts for each development stage), and drought resistance (destructive harvest for NSC analysis). Non-destructive measurements (e.g., seedling height, stem diameter) were obtained monthly by taking images of seedlings using an iPhone for ImageJ analysis (Schneider et al. 2012) and manually measuring seedlings with a ruler or calipers. Destructive measurements (e.g., root surface area, root:shoot biomass) were obtained on eight seedlings per family at 4-, 6-, 8-, and 12-months post-sowing to obtain information for functional leaf and root traits, biomass, and NSCs. During this process, leaf trait data were obtained using iPhone imaging for ImageJ, root trait data were collected using a desktop scanner to obtain 3D root scanned images for Rhizovision analysis (Seethepalli and York 2020), and fresh and dry biomass values were collected using a scale for leaves, stems, and roots. Phenology data were obtained by conducting weekly seedling counts. During these counts, all seedlings were examined to designate the development stage (emerged, establishment stage 1 (cotyledons surrounding needle bud), and establishment stage 2 (needle burst)). A family was considered as successfully established if the family had an establishment rate of > 50% at nine months post-sowing (Overton et al. 2016). For drought resistance data, NSC samples were obtained post-destructive harvesting by following the Ulrich Lab protocol (adapted from Landhäusser et al. 2018).

Measures of Success
These measurements will be used to obtain information that is paramount for outplanting families that will succeed in the face of WPBR and climate change. Specific measures of success include ranking all families (1-50) (objective 1), USFS seed zones (1-8) and BCFS locations (1-5)(objective 2) for establishment success rate. Using statistical testing, the average date post-sowing for reaching the emergence and establishment stages will be obtained for each family (objective 3) and correlated with growth and drought resistance traits (objective 4). Lastly, a GIS model will be used to test for correlations between climate and successfully established families (objective 5). A small proportion of seedlings were harvested for NSC analysis as a cost-effective and training-efficient method for an MS thesis. Obtaining these measurements through a common garden study is one of the first steps towards identifying how climate change may impact WBP seedling growth traits and regeneration success in the field.

TREASURER'S REPORT

2022 WPEF Treasurer's Report

Glenda Scott, Treasurer

Wow, what a year! We closed the 2022 books with over $122,000 in the treasury - this reflects an exciting year of various projects and commitments. Over half of our income was largely for the preparation of the National Whitebark Pine Restoration Plan and for contracts focused on whitebark pine and bristlecone pine genome work. As we look at these endeavors and financial supporters, we must also reflect on the importance of the increased support from new and existing members and the advocates of high elevation ecosystems. We are ever thankful for this support.

Outlook
The Foundation will continue with the projects and commitments of 2022 as we move into 2023 and beyond. The large,

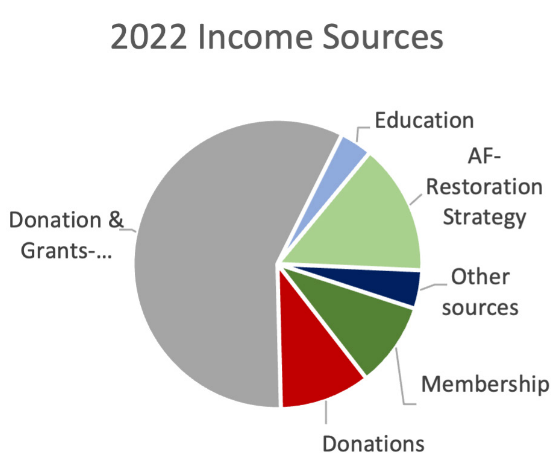
dedicated donations and partnerships have enhanced our fiscal position to support this critical work. We look beyond 2022 however, and see that we must increase financial backers to sustain our work. The contracts for the genome sequencing will be awarded in 2023 causing a steep decline in our balance compared to 2022 and the National Restoration Plan (NWPRP) preparation will conclude in 2023 potentially reducing our past income levels. We strive to enlist the support of advocates to expand our work to meet our mission.

Essential to the Foundation's financial health and mission are membership dues and generous donations from members and supporters, like you!. Thank you to those who have been able to contribute! We hope you will reach out to your colleagues, friends and enthusiasts to join us in supporting WPEF.

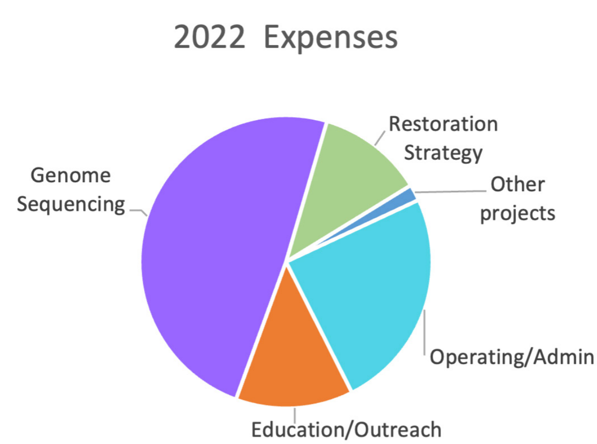
The BOD is conscious of our fiscal responsibilities and scrutinizes spending and strategies for good financial practices. Please direct question or concerns to Glenda Scott, Treasurer (glenda.scott@whitebarkfound.org) or any board member, or Julee Shamhart, Executive Director (julee.shamhart@whitebarkfound.org). The detailed treasurer's financial report and IRS 990EZ are available upon request.

Financial Summary

2022 Beginning Balance	$135,699.61
Income	+$129,946.48
Expenses	-$143,641.37
2022 Year-end balance	***$122,004.72***



Membership Dues (9%)
Donations (10%)
Donations & Grants-dedicated (58%)
Education (4%)
AF-National Restoration Plan (15%)
Other (4%)



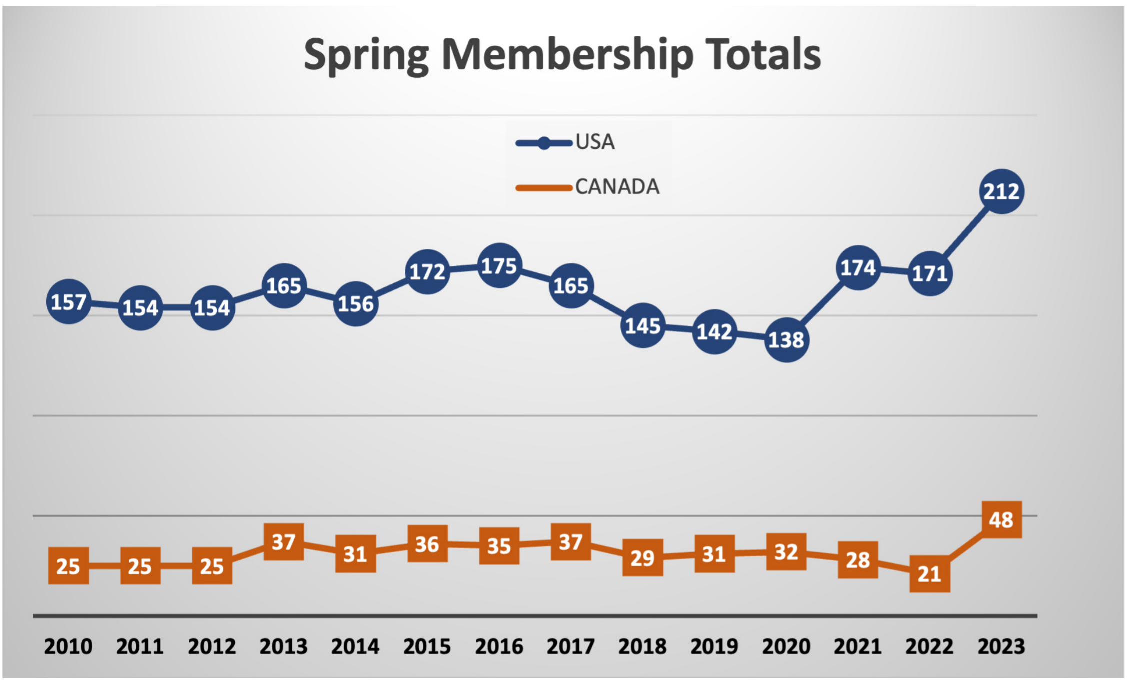
Education and Outreach (13%)
National Restoration Plan (12%)
Genome Sequencing (49%)
Operations and Administration (24%)
Other Projects (2%)

MEMBERSHIP

Michael Murray, Membership Coordinator

Behold! Our numbers continue to rise. Membership in the foundation not only provides financial support for the education and restoration of a high mountain pines, but also allows for the networking necessary to bring the considerable expertise of the 260-plus members (North America) together to meet our goals. In Canada, we have completed a Membership Strategic Plan. Our goal is to double our membership tally by 2025.

Our esteemed Board Member, Donna Kridelbaugh, has amped up our social media presence. Please share our organization! If you're on social media, there's many ways to keep WPEF in the spotlight. For example, share posts from our Facebook Page, or submit your own media links to media@whitebarkfound.org. Donna has also helped us transfer and train for our new membership software – thanks Donna!



This may be your last issue of Nutcracker Notes. The membership year corresponds with the calendar year. Can't remember when you last signed-up? Consider choosing the automatic sustaining option, aka "Yearly". This will automatically renew you every year! For USA, go to: https://whitebarkfound.org/membership/. For Canada, go to https://whitebarkpine.ca/membership/ and choose the "Recurring" option. You can also email me to check on when your last sign-up was: michael.murray@whitebarkfound.org.

Nominations for 2023 Whitebark Pine Ecosystem Foundation Board Elections

Our bylaws dictate that elections are to be held every year for various positions – this way there is always a rotation of experienced Board Members and Executive Committee officers, and we would never face a complete turnover of officers and the uncertainty that could ensue. Please consider running for one of these positions!

Board members and officers commit to working collectively to advance the business of the WPEF and the conservation and restoration of high elevation pines. This includes attending four board meetings per year, one of which is in conjunction with the annual WPEF science meeting and field trip in mid-to-late September somewhere within the range of whitebark pine, along with three virtual meetings in winter, spring, and summer. To find out more about the duties of these positions, please contacta current board member.

Bob Keane Associate Director: bob.keane@whitebarkfound.org

Nomination Form – Whitebark Pine Ecosystem Foundation

Nominations are being sought for the following SIX (6) positions, to begin serving on the Board of Directors in October 2023. All positions are for a 3-year term:

- Associate Director
- Membership Coordinator
- Treasurer
- Board Member #3
- Board Member #6
- Board Member #7

If you are interested in a position and want to know more about that position, we can email you a copy of the Executive Handbook which has detailed descriptions of the responsibilities of each position.

RULES:

- All board members can serve up to 3 terms consecutively [Bylaw E(h), E(i) and F(a)].
- A nominee to the BOD does not have to be a member of the WPEF, but voting privileges on the BOD are restricted to members in good standing [Bylaw E(c)], so once elected the nominee must become a member.
- Any nomination must be made by 2 members in good standing [Bylaw F(b)(i)], and consented to by the signature of the nominee; signatures can be on one form, or on separate forms.
- **Only one nomination per form**. If you need more forms, please copy this one, or download another one from our website www.whitebarkfound.org .
- Send nominations by mail [Box 17943, Missoula, MT, 59808], E-mail bob.keane@whitebarkfound.org).
- Complete nominations must be postmarked/dated no later than **30 MAY 2023.**

We, the undersigned, nominate ___________________________________ for the position of

MEMBERSHIP ___ ASSOCIATE DIRECTOR ___ TREASURER ___ BOARD MEMBER ___ [s*check ONE*].

Nominator #1: ____________________ ____________________ ____________________

Signature *Print Name* *E-mail address*

Nominator #2: ____________________ ____________________ ____________________

Signature *Print Name* *E-mail address*

Nominee: ____________________ ____________________ ____________________

Signature *Print Name* *E-mail address*

WHITEBARK PINE

ECOSYSTEM FOUNDATION

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