National Whitebark Pine Restoration Plan

Restoration and Management Treatments for Whitebark Pine Communities
Best Management Practices, version 3.15.21

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I. Purpose.

The overarching goal of whitebark pine conservation and restoration is to develop and sustain healthy and resilient whitebark pine communities in the face of current and future challenges.

This document represents an initial component of the National Whitebark Pine Restoration Plan (NWPRP). It reviews in outline form the key management treatments and actions that are currently used for whitebark pine (*Pinus albicaulis*) conservation and restoration. Whitebark pine was proposed for listing as a Threatened species by U.S. Fish & Wildlife Service under the Endangered Species Act on December 2, 2020 (U.S. Fish & Wildlife Service 2020). The ecological importance of whitebark pine has previously been well-described (Tomback et al. 2001, Tomback and Achuff 2010, Keane et al. 2012, U.S. Fish & Wildlife Service 2020).

As part of the process of developing the NWPRP, details concerning best practices and application of these management actions were discussed at an inter-agency teleconference workshop facilitated by the Whitebark Pine Ecosystem Foundation in collaboration with American Forests and the U.S. Forest Service, August 31, 2017. Workshop participants submitted suggestions and comments as follow-up (see Acknowledgments); other individuals have added material on key actions since the workshop. This outline serves as the basis for an expanded document now in preparation.

Keane et al. (2012), presented a basic strategy for developing a range-wide restoration plan for whitebark pine. The restoration component to this strategy centers around four management principles: conserve genetic diversity, promote rust resistance, save seed sources, and employ restoration treatments. These principles are served by ten management or conservation actions that could in part be considered a work-flow plan:

1) *Assess condition*. Fundamental to restoration is the need to assess status and trends of whitebark pine health at local scales in specific geographic areas.
2) *Plan activities*. With local scale information, appropriate conservation and restoration actions can be planned.
3) *Reduce disturbance impacts*. These include actions that reduce the risk of destructive fire or mountain pine beetle attack on whitebark pine.
4) *Gather seeds*. Seed collections are used for multiple purposes, including gene conservation, conservation of genetic diversity, and growing seedlings.
5) *Grow seedlings*. Seedlings are grown for blister rust screening trials to identify parent trees with genetic resistance. Seedlings from putative resistant trees and trees found to have genetic resistance are grown operationally for planting efforts.
6) *Protect seed sources*. Once resistant or “plus” trees have been identified through screening efforts, they require protection from wildfire and mountain pine beetles.

7) *Implement treatments*. These are on-the-ground restoration treatments that include the use of silvicultural techniques and prescribed fire to create opportunities for whitebark pine regeneration, and reduce competing vegetation and fuels.
8) *Plant seedlings*. Planting seedlings that are grown from parent trees with resistance to white pine blister rust enhances natural selection by increasing resistant genes in populations. Direct seeding may, in some areas, become an important alternative. Because cone production dwindles in unhealthy populations, planting and seeding actions become especially critical.
9) *Monitor activities*. Monitoring the efficacy of restoration actions is important for providing feedback on implementation. Successful outcome from treatments cannot be assumed. Some actions may need to be modified or repeated over time.
10) *Conduct research*. New technology or approaches will improve or expedite all efforts.

II. Fundamental statements to set context concerning threats to whitebark pine and a restoration strategy.

This section provides context for the management actions discussed in this document. It consists of general statements developed at the 2017 workshop summarizing current views on threats to whitebark pine and management strategies.

Whitebark pine (*Pinus albicaulis*) is experiencing multiple threats across its range. These vary geographically but include the disease white pine blister rust (WPBR), caused by the naturalized non-native pathogen *Cronartium ribicola*; current and future mountain pine beetle (MPB) (*Dendroctonus ponderosae*) outbreaks; advancing succession due to fire exclusion practices but also larger, more severe wildfires; and the impacts of climate change.

1. Climate change potentially affects whitebark pine regeneration, distribution, and abundance; supports MPB outbreaks; and alters fire regimes. Its effects on the spread of *Cronartium ribicola* geographically and infection dynamics are not clear. These effects may depend on the specific regional climate change that is experienced.

2. *Cronartium ribicola*, infectious only to five-needle white pines and its alternate hosts, is currently and potentially the most persistent and widely distributed threat to whitebark pine populations, affecting seedlings, saplings and mature trees. The combination of WPBR and MPB reduces seed production and accelerates population losses.

3. *Cronartium ribicola* is still spreading and intensifying across the range of whitebark pine.

4. Several approaches to combat WPBR have been tried during the early history of its detection and spread in five-needle white pines. Where the disease is prevalent, the only successful approach to building resilience to *Cronartium ribicola* in whitebark pine populations is to increase the frequency of genetic resistance within populations by planting seedlings grown from seeds collected from trees that have been screened and found to have genetic resistance or by directly sowing seeds from these trees. Trees found to have genetic resistance must be protected from MPB.

5. In some geographic regions where blister rust infection has led to high mortality over decades, seedling planting and seed sowing, using seeds from trees that have been screened and found to have moderate to high genetic resistance, are the only way to return or maintain functional whitebark pine on the landscape.

6. Restoration actions, where applicable, should include climate change mitigation at a local or regional geographic scale. Mitigation strategies may include targeting certain genotypes to use to grow seedlings for planting or for direct seed sowing, where to plant seedlings or sow seeds within the local distribution, and where to apply thinning or prescribed fire treatments.

7. In areas where whitebark pine is still relatively healthy, proactive management should be a priority. Actions should include gene conservation collections to capture genetic diversity (tissues and seeds from individual trees that are tagged and georeferenced) for archiving and genetic screening of cone-producing trees to determine the frequency and distribution of *Cronartium ribicola* resistance. Seed source trees with genetic resistance should also be protected from MPB and fire. If natural genetic resistance is present at high levels, light prescribed burning and thinning may encourage natural establishment of seedlings with rust resistance. Planting opportunities will hasten the increase in resistance in target populations. Management of these forests to reduce future WPBR-caused mortality and diversify the age-class structure of whitebark pine across the landscape will help limit future MPB outbreaks, as will thinning.

8. Management of whitebark pine, in contrast to wind-dispersed pines, is both complicated and expedited by the pine's dependence on Clark's nutcracker and complicated by cone cutting by red squirrels. Where cone crops are much reduced, seeds from resistant trees may be lost to pre-dispersal predation or not be dispersed by nutcrackers. In stands where resistance has increased through planting, direct seed sowing, or natural regeneration, and trees reach maturity, nutcrackers will potentially spread resistance by caching seeds in adjacent areas and to distances as great as 30 km. This concept is fundamental to devising a core area restoration plan.

III. Selected restoration protocols and applications.

In this section, several key management practices that pertain to conservation and restoration are described. In some cases, specific practices will vary geographically or for areas where not yet applied, require further evaluation.

A. Conserve genetic diversity: Seed collections and seed archiving.

Several agencies have collected seeds for archiving and conservation of genetic diversity. These collections are an important means of preserving genetic diversity, as populations decline from blister rust and mountain pine beetle. They can be used for determining the distribution of genetic diversity within and among populations and for assigning seed zones, establishing common gardens for determining adaptive traits including cold hardiness and drought tolerance, and for determining the prevalence of genetic resistance to white pine blister rust. They may also be used as part of climate change mitigation protocols, as these are developed.

- Recent information suggests that seeds stored around -16°C with less than 10% moisture may remain viable for decades.
- Whitebark pine seed collections dating from 1978 to 2009 were recently tested for viability and found to have germination rates ranging from 0 to 96% with a mean germination success across all collections of about 47% (Sniezko et al. 2017a).

B. Promote rust resistance.

The primary means to increase resilience to white pine blister rust in whitebark pine populations is to increase the frequency of genetic resistance within populations, thereby speeding up the effects of natural selection. There are multiple actions connected with this process including the identification of seed trees with rust resistance and planting progeny from these trees. Planting seedlings or sowing seeds can be construed as both promoting rust resistance and restoration treatment.

Relevant terminology:

Genetic resistance: Whitebark pine populations naturally have some genetic resistance to blister rust. The quantitative resistance (i.e., partial resistance) found in whitebark pine is suspected to be conferred by multiple genes (polygenic) with frequencies that vary among populations. There are several different resistance mechanisms (resistant phenotypes) within whitebark pine, and each may be produced by different genotypes (e.g., Hoff et al. 2001, Sniezko et al. 2011). Because not all progeny from a seed tree with quantitative resistance will inherit the resistance traits, the screening process determines which screened plus or seed trees provide the best (highest) proportions of resistant offspring among the trees tested, particularly in comparison to the most susceptible (least resistant) genotypes. A sufficient number of seed trees shown to have some heritable resistance must be identified in order to provide adequate genetic diversity for restoration actions. Seed orchards through controlled pollination enable improvement in the proportion of progeny with resistance.

Seed tree (seed source with unknown resistance): A healthy, cone-bearing tree selected from an area of moderate to low to no blister rust for seed collection. The tree has not yet undergone screening for blister rust resistance. These trees, if geo-referenced and tagged, can be candidates for resistance screening to obtain baseline frequencies of resistance in threatened populations, and, if shown to have resistance, may provide *in situ* seed sources for growing seedlings for planting.

Plus tree (putatively resistant seed tree): A relatively healthy geo-referenced and tagged tree from a stand with high infection levels of blister rust and mortality. The tree is a candidate for resistance screening.

Elite tree (resistant seed source): A seed or plus tree confirmed through resistance screening to have heritable (genetic) resistance (or reduced susceptibility) to blister rust. The level of resistance provided to progeny is yet undefined and may be in relation to other screened trees to date within the stand or geographic area. Note that there are several different phenotypes that confer resistance to *Cronartium ribicola*, each the result of a different genotype (Hoff et al. 2001, Sniezko et al. 2011)

Putatively resistant seedlings: Seedlings grown from seeds from plus trees, with the assumption that some of the seedlings will have some degree of genetic resistance. Often, seeds are combined into a bulked lot with unknown resistance**.** Putatively resistance seed lots can be screened to provide an estimate of the frequency of resistance for determining appropriate planting densities.

Resistant seedlings: Seedlings grown from seeds from elite trees, or a mix of elite trees and plus trees. Not all of these seedlings will carry the resistance traits, but seedling survival is expected to be greater than for seedlings grown from putatively resistant seed trees or seed trees not selected in the field for resistant phenotypes. Survival may be **50% or lower** because of cross-pollination or recombination. Bulked resistant seed lots can be screened to provide a better estimate of the frequency of resistance for determining appropriate planting densities.

Improved resistant seed: Seeds harvested from a seed orchard. Controlled pollination can increase resistance and the proportion of genetically resistant progeny.

1. <u>Selecting trees, screening for genetic resistance, and establishing seed orchards.</u>

a. *The range of whitebark pine has, in part, been divided into provisional seed zones, based on the best information (genetic and common garden) available.* These seed zones serve as the basis for selecting plus trees for genetic screening. By definition of a seed zone, seeds from any tree within a seed zone will be adapted to most areas within that seed zone. Thus, seeds from elite trees from one location can be used to grow and plant seedlings anywhere within that seed zone. Seed zone designation may be revised as indicated by results from common garden studies and changing climate.

- Seed zones should be identified for all geographic regions within whitebark pine's range.
- The rational for using seed zones is to minimize loss of seedlings from maladaptation.
- Five seed zones are identified now for the Inland Mountain West based primarily on unique population markers (Mahalovich and Hipkins 2011).
- For the Inland Mountain West, at least 100 plus trees are recommended per seed zone for initial resistance screening. The number of plus trees ultimately required to screen depends on the proportion of trees with relatively high resistance.
- For small or isolated distributions, 50 plus trees are recommended.
- For populations not yet invaded by WPBR, proactive rust resistance screening of seed trees can identify elite trees.

- Screening seed trees and plus trees for heritable resistance should be a priority across the range of whitebark pine. A pool of rust-resistant elite trees is important for restoration treatments, proactive restoration, and climate change mitigation in different seed zones.
- The goal is to maximize genetic diversity for restoration, which entails identifying as large a number of elite trees as possible. Elite trees will serve as seed sources for growing seedlings or sowing seeds for restoration purposes.
- How many elite trees are recommended per seed zone? A recommendation from conservation genetics is the 50/500 rule, but these numbers are inadequate to capture rare alleles. Also, these numbers refer to effective (actual breeding) population size, which is lower than population size.
- Example: Results from a resistance screening trial (R.A. Sniezko, in prep.) from the Pacific Northwest. From Seed Zone A, 17 families of seedlings (a family = seedlings from one tree) were screened, and the mean seedling survival rate across families was 2.3% (range 0% to 20.7%) with only one family (5.8% of the 17) showing over 20% survival. If 20% or greater survival (in high rust areas) were desired for planted seedlings in that seed zone, and if a minimum of 50 elite trees were needed, then about 850 plus trees would require screening from that seed zone**.** Generally, the prevalence of rust resistance varies geographically, and other areas within the same seed zone may have higher success and require fewer trees for screening.
- Rust virulence varies geographically, and screening protocols should use multiple strains of *Cronartium ribicola*, which means that infected *Ribes* leaves are collected from several geographic areas.
- Determining the extent of climate/edaphic adaptation that we can expect of whitebark pine genotypes from a given seed zone might be useful for climate change mitigation. Mixing genotypes at a given location with those from a seed zone or ecoregion just to the south or from a climate zone projected to be more similar to the future climate might be an effective mitigation strategy.

b. *Stand-level criteria are applied to provide guidance for plus tree selection for resistance screening.* Stand level criteria will vary with the geographic region and prevalence of blister rust infection and mortality. As a reminder, the goal is to maximize genetic diversity for restoration, which requires identifying as large a number of elite trees as possible. Elite trees will serve as seed sources for restoration purposes.

For the Inland Mountain West program:

- A 100-tree survey for blister rust infection levels has been recommended to obtain base-line information for each forest stand prior to plus tree selection. This survey should also include the percent of trees killed by MPB, and whether the beetle mortality is recent.
- The highest probabilities of finding a tree with rust resistance occur in stands where blister rust infection or mortality is 90% or greater, but high infection and mortality are found in only a portion of whitebark pine's range.

- In stands with infection levels ranging from 50 to 90%, the healthiest mature trees should be selected for plus trees. If no healthy, mature trees can be found, individuals with no more than five cankers should be selected as plus trees.
- Plus trees and seed trees should be separated by at least 200-300 feet and free of insect infestation and other diseases.
- Where blister rust mortality and infection levels are high, trees that have few cankers and that show tolerance (i.e., long-term survival with infection) to cankers should be considered for screening. In areas of no to low blister rust infection, seed tree selection based on field phenotype with respect to WPBR resistance is not possible, but selection should then be based on good cone production, no symptoms of insect infestation or disease, vigorous growth, and suitability of tree for climbing.
- Whenever possible, seed tree selection should be canker-free. Trees that show tolerance to cankers should be considered as seed tree candidates. In areas of no to low blister rust infection, selections of mature, healthy trees will be essentially random.
- Selected plus trees in all cases should be those capable of bearing moderate to good cone crops, both pollen and seed cones, easily and safely climbed, with spreading crowns. Minimum age varies with elevation and location. High elevation trees should be a minimum of 60 to 80 years of age; low elevation trees may grow faster and meet criteria at earlier ages.

For geographic regions with lower blister rust infection levels or for dispersed (widely-spaced) trees on landscape, there is guidance from the Inland Mountain West program for selecting plus trees:

- Plus trees should be those relatively free of blister rust in comparison to the infection level of the stand as a whole.
- Stand level infection levels may be best to determine tree selection criteria.
- Where blister rust infection levels are low, tree selection for resistance screening is based on general tree health, tree age, cone production, sturdiness (for tree climbing), and crown volume.

For geographic regions with no to very low blister rust infection levels, such as the Great Basin ranges and southern Sierra Nevada, plus tree selection must be essentially random but guided by phenotypic traits:

- Tree selection for resistance screening is based on general tree health, tree age, cone production, sturdiness, as above.
- The initial target number of plus trees within each seed zone may be 100.
- The target number of plus trees identified for screening will ultimately depend on the frequency of trees (families) found to have relatively higher levels of genetic resistance to WPBR.
- If few plus trees are found with high genetic resistance, then more plus trees must be identified and screened.

c. *Standards that should be met for <u>Cronartium ribicola</u> resistance screening for whitebark pine.* **Screening follows a protocol whereby seedlings grown from seed or plus trees are exposed to high densities of *Cronartium ribicola* spores under controlled conditions and then followed over time to see if they develop blister rust symptoms or show resistance.**

- Each screening trial should include seeds from the same seed lots that have been previously tested and shown to be fully susceptible. Many whitebark pine are highly susceptible, and 100% of progeny from these susceptible trees are expected to become infected during the blister rust resistance screening process.
- One or more known resistant (elite tree) controls should be included in testing to ensure that the inoculation level is not so high that all resistance mechanisms are overcome.
- Spore loads should be set at a level that achieves 100% infection of known susceptible controls for given inoculation and culture conditions.
- Inoculum used for screening should be from diversified regional sources (mixed population of basidiospores).
- Whitebark pine seedlings are inoculated when there is adequate top growth. The seedling age depends on seed source and geographic region, but growth is usually sufficient when seedlings are 2 to 3 years of age.
- Seedling post-inoculum scoring protocols may differ according to seed zone (geographically) but could be generally standardized.
- Infection symptoms and resistance reactions are expressed in seedlings at different and variable time periods post-inoculation, depending in part on conditions.
- Field trials should be established to verify the results of resistance screening and confirm that the inoculum source (spore density) was adequate, and the resistance expressed in the artificial inoculation trials is expressed under field conditions. Screening occurs under artificial conditions, and conclusions about resistance should be made cautiously until verified by field trials.
- Field trials may involve (1) outplanting surviving seedlings from blister rust screening (inoculation trials) to observe the durability of resistance, or (2) outplanting seedlings grown from seeds from a previously screened tree to verify the stability or durability of resistance over time. (Infected seedlings planted at new locations should be monitored.)
- Field trials should ideally include trees with different resistance phenotypes. Field trials must include known (tested) susceptible seed lots to serve as controls to provide evidence that the test seedlings are being challenged by the rust.

d. *Seed orchard establishment as an operational seed source.* **Once a number of resistant (elite) trees are identified for a seed zone, the establishment of one or more seed orchards for shared multi-agency and tribal use facilitates access to seeds with a high likelihood of resistance for growing seedlings for operational planting. Each seed**

orchard represents a significant cost for both establishment and maintenance, and this management practice has both pros and cons. Once established, the benefits are clear. More discussion about the merits of seed orchards may be useful.

Pros:

- Genetic gain on both maternal and paternal sides, through cross-pollination.
- Ability to treat for insect and disease issues and protect trees from fire.
- Can apply treatments to stimulate cone production, overcoming periodicity.
- Once established and producing seeds, seed orchards are very cost effective.
- With orchards, we do not need to rely on dispersed elite trees as a seed source, which would require more than 20 trees to provide sufficient genetic diversity for planting operations (but see correct protocols for growing seedlings).
- Dispersed elite trees are vulnerable to MPB, wildfire, and other damaging agents.

Cons:

- All valuable trees together in one area increase vulnerability to disease, insects, and fire.
- Experience indicates that typically minor insect outbreaks may become larger problems under orchard conditions.
- Orchard must be protected against wildfire.
- Operational cone production from seed orchards will require years after orchard establishment. Restoration planting of seedlings should not be delayed.
- The numbers of individual trees in orchards should be as high as possible to insure genetic diversity.

What criteria are used for selection of trees (scion) for seed orchards?

- Target minimum of 30-60 unrelated elite trees from a given seed zone.
- Tree selection should diversity resistance mechanisms within an orchard.
- Consider adding/diversifying genetic diversity over time.

2. <u>Cone collections, seed germination, growing seedlings, and planting seedlings</u>.

a. *The processes of seed collection and growing seedlings are important both for resistance screening and operational seedling production.* These have been in practice now for more than 20 years.

- For selected trees (i.e., seed, plus or elite trees) with good cone production, cones are caged in July with hardware cloth by tree climbers or with tree-tongs (e.g., Murray 2007) to prevent cone cutting by squirrels and removal of unripe seeds by Clark’s nutcrackers.
- Trees are climbed again in September to collect cones.
- Seed germination and seedling growing protocols appear to be successfully implemented at an operational level (e.g., Burr et al. 2001, Kolotelo et al. 2001, Sniezko et al. 2017a)

- Seeds for growing seedlings for planting often are from bulk lots harvested from dispersed plus trees or elite trees and phenotypically healthy trees from areas known to have relatively high resistance levels. The bulk lot must be from at least 20 seed source trees to provide sufficient genetic diversity.
- These bulked seed lots should be screened for resistance to justify the restoration planting effort and to estimate planting densities.
- Concern has been expressed that the long time-frame for resistance screening might discourage planting efforts. Planting highly susceptible trees, however, is not cost effective. Seeds from trees with untested resistance should not be used for rehabilitation or restoration unless the seed sources are in areas known to harbor high levels of blister rust resistance.
- Eventually, bulked seed lots can be primarily from elite trees, as they are identified.
- Eventually, seeds from orchards will provide the highest likelihood of resistance among seedlings.

b. *Planting seedlings/sowing seeds from resistant seed sources both promote rust resistance and comprise restoration treatments, especially where blister rust infection and potentially where MPB mortality are high (depending on understory composition).* General planting guidelines including where and where not to plant have been successfully implemented (e.g., McCaughey et al. 2009). Recommendations are included that incorporate some mitigation for climate change. Questions about some potential actions are noted.

- Plant robust seedlings with well-developed root systems.
- Planting densities are generally 175-200 seedlings/acre. Planting density may vary geographically and with seed source and expectations of seedling mortality.
- Plant in competition-free environments, avoiding encroachment by larger or more shade-tolerant conifers.
- Areas recently burned by wildfire are highly suitable for planting.
- Preparation of site may be by prescribed burning to eliminate vegetation.
- Where feasible, plant in stands with high mortality from MPB to speed regeneration, take advantage of open conditions, and to increase genetic resistance to blister rust, depending on understory composition.
- Wait for bark to slough off trees first before planting in stands with high MBP mortality or seedlings may be damaged or covered.
- Avoid dense vegetation, grasses, and beargrass (*Xerophyllum tenax*), in the Inland West in the immediate vicinity of the seedling.
- Provide shade for part of the day on southern and western aspects by using natural objects (rocks, fallen trees, deadfall), but avoid stumps in areas of known root disease and post-fire snags. In most plantings, wood debris can be positioned to provide shade.
- Plant during moist periods, avoiding summer heat and drought. The most favorable times will vary geographically. For climate change mitigation, include planting on cooler

topography, such as northerly-facing slopes and in local areas supporting cooler conditions.

- Direct seeding (sowing) may be an efficient alternative to planting seedlings in some but not all regions (e.g., Schwandt et al. 2007, Pansing et al. 2017). The utility of this practice may be limited by the availability of seeds from elite trees or other seed trees likely to have genetic resistance. Ideally seeds should not need to be scarified and stratified for direct seeding. They should be sown in sites similar to those recommended for seedlings (above).
- For climate change mitigation, select moister aspects and microsites within the tolerance range of whitebark pine seedlings, but avoid areas of competing vegetation. Northern aspects and cooler slopes may be important for planting at lower latitudes.
- Plant first at the highest elevations within the targeted area or burn for climate change mitigation.
- Consider planting in upper subalpine-lower treeline ecotone (just below or transitioning to flagged and krummholz) communities; these do not require seedbed preparation. These communities are important for snow retention and watershed protection, and these zones are where trees are responding to warming effects.

Frequently asked questions that require further study to answer

- Should areas within seed zones be rated for blister rust hazard (conditions favorable to blister rust)? Should we avoid planting in high hazard sites?
- Does inoculation of planting media with ectomycorrhizal (ECM) fungi significantly improve seedling growth and survival in the field? To what extent will natural ECM colonization occur in the field?
- How far can seeds be moved northward (e.g., 2°, 4°, etc.) to be added to local plantings to provide resilience for changing climate? Information based on a tolerance analysis would be highly valuable.

C. <u>Save seed sources and seed lots</u>.

After field identification of seed trees with potential genetic resistance to blister rust, these trees must be protected from all threats during the screening process. Trees found to have genetic resistance must be protected from all threats, given that they are critical to restoration efforts and represent an investment of resources.

- Seed trees that are designated plus trees and elite trees must be **protected** from MPB attack as long as there is any threat.
- For short-term protection against MPB, options include use of the anti-aggregation pheromone, verbenone, or preventive insecticides/pesticides. Pesticide application requires state certification and product knowledge. Mountain pine beetles naturally produce verbenone to disperse adult beetles away from a fully colonized tree. Verbenone has been synthesized and is available for ground application in slow-release pouches that can be stapled to trees (Anonymous "Using Verbenone...") and in a wax

emulsion matrix applied with a caulking gun (SPLAT[R] Verb) (Fettig and others 2016). Either verbenone product can be used in an area (stand) or individual tree treatment to protect non-infested pine trees when there is MPB activity threatening an area. Verbenone has also been formulated in small inert polymeric flakes that can be aerially applied to pine forests by small aircraft (Gillette et al. 2012) and would be most economical for remote areas. Verbenone does not always protect all treated trees or areas, particularly when MPB populations are extremely high. Preventive insecticides, such as carbaryl, can be 100% effective in protecting individual trees from MPB when properly applied to the bole (Anonymous 2011 "Using Insecticides…")

- Extra seed collections from known susceptible trees are also useful to provide control seedlings during the resistance screening process. Susceptible trees may become more scarce with time as they are eliminated by natural selection—their progeny may become less susceptible (due to resistant pollen cloud). Over time, the baseline for what constitutes "fully susceptible" will change if new seed collections are needed. Retaining and stocking seeds from susceptible individuals is important for maintaining comparison standards.
- For long-term protection, silvicultural treatments such as thinning and pruning can protect whitebark pine from MPB attack (Sturdevant et al. 2015).
- Plus trees, and especially elite trees, must be protected from wildland fire. Their locations should be mapped, shared, and incorporated into the unit's fire management plan.
- Seed orchards should have high priority for protection from all threats.

D. Apply treatments.

In addition to planting treatments, silvicultural treatments and prescribed fire are used in different ways to encourage natural regeneration through nutcracker caching, reduce competition from shade-tolerant conifers, or encourage better whitebark pine growth. At the same time, plus and elite trees, as well as productive stands, must be protected from wildland fire.

1. Silvicultural treatments as a restoration tool in stands experiencing advancing succession.

***The objective of silvicultural treatments is to remove competing, faster-growing conifers in successionally-advanced stands in order to retain cone-producing whitebark pine or to encourage whitebark pine regeneration or to enhance fuels for prescribed burning*. Some specialized treatments are designed to create open areas for natural regeneration.**

- Prescriptions must be tailored to individual stands. This approach may be particularly useful for proactive restoration efforts.
- General prescriptive guidelines for treatments are presented in Keane and Parsons (2010) and Keane et al. (2012, p. 73-83) specifically for the northern Rocky Mountains.

More detailed prescriptions, especially for other regions, are currently under development.

- These treatments are most easily accomplished when target stands are near roads and on gentle terrain. Types of treatments (Keane et al. 2017a, Keane 2018):
  - *Nutcracker openings* (patch clearcuts,1 to 30 acres) encourage seed caching and simulate mixed severity burns.
  - *Group or individual tree selection cuts* where all species except whitebark pine are removed from an area.
  - *Thinning or "weeding"* where all faster-growing conifers are cut (subalpine fir, spruce, mountain hemlock, and lodgepole pine). This can be followed by burning to eliminate understory. Low densities of lodgepole pine may be left on site, since they do not produce closed canopies.
  - *Thinning ("daylighting")* clears all competing conifers in a circle around a cone-bearing whitebark pine in a radius about the height of the canopy. This has not been tested for effectiveness. This treatment has been found to reduce the risk of MPB attack (Sturdevant et al. 2015).
  - *Girdling* as a rapid way of killing competing trees. Trees must be girdled below the lowest branches, which can otherwise become new boles.
- Lodgepole pine slash should be removed from sites to provide open areas for seed caching and to prevent secondary bark beetles from moving from slash into whitebark pine.
- If the competing trees are merchantable, commercial contracts can help fund the project.
- Silvicultural treatments can reduce and eliminate understory fuels, as well as understory competing conifers, which will protect high value (e.g., plus trees or screened resistant whitebark pine).
- Removal of understory conifers increases likelihood of *Ribes* spp. spread because seeds in the soil seed bank germinate or shrubs proliferate in response to mechanical disturbance of underground parts (Zambino 2010).

2. Wildland fire management as a restoration tool, and fire management.

The Rocky Mountain distribution of whitebark pine and some areas in the Pacific and inter-mountain region experience frequent fire, which is key to renewal of successional communities. **Whitebark pine in the Rocky Mountains historically experienced three types of fire regimes: non-lethal (surface), mixed severity, and stand-replacing (lethal). Mixed severity and stand-replacing are most common (Keane 2018). Other regions across whitebark pine's distribution, including the Great Basin Ranges, most of the Sierra Nevada, areas within the Pacific Northwest and coast ranges, and north of about 50° in Canada are dominated by open communities of "climax" or self-replacing whitebark pine at subalpine and treeline elevations. These communities may support pure stands of whitebark pine or whitebark pine co-dominant with other conifers (Arno**

and Hoff 1990, Tomback and Achuff 2010). Wildland fire management involves wildfire suppression, wildland fire use, restoration treatments, and mitigation.

a. **Prescribed fire as a management tool for stands experiencing advancing succession in the Rocky Mountains.**

- Prescribed burning cannot be controlled as well as silvicultural techniques.
- Prescribed fire can remove potentially competing understory more effectively than silvicultural methods.
- Prescribed fire runs the risk of killing whitebark pine, including plus and elite trees.
- Whitebark pine in the Rocky Mountains historically experienced all three types of fire regimes: non-lethal (surface), mixed severity, and stand-replacing (lethal). Mixed severity and stand-replacing are most common.
- The three fire regimes can be simulated with prescribed fire for specific applications. Surface fires remove conifer understory; mixed severity fires open the canopy and create clearings; high intensity fires kill trees over a large area, removing competition and creating opportunities for regeneration.
- General prescriptive guidelines for treatments are presented in Keane and Parsons (2010), Keane et al. (2012, p. 73-83), and Keane (2018) for the northern Rocky Mountains. Detailed prescriptions are currently under development.
- Understory fuels can be augmented through silvicultural treatments (tree felling) to achieve a consistent and longer burn.
- With climate change increasing fire frequency and severity, prescribed fire may become more restricted in use.

b. **Managing fire in whitebark pine stands. Wildfires in whitebark pine communities can either be fully suppressed, partially suppressed, or allowed to burn (wildland fire use, WFU).**

- Full suppression requires that crews suppress fires while they are still small and has a high success rate if implemented.
- Partial suppression (spot suppression) involves protecting small areas, such as those supporting plus trees, through the use of flame retardant or water drops.
- WFU can be used effectively as prescribed fires (see above). These fires are generally lightning ignitions that are allowed to burn under an existing fire plan.
- Uncontrolled wildfires may also be beneficial in whitebark pine communities that are experiencing advancing succession and poor health conditions. They support proactive restoration and create opportunities for planting rust-resistant seedlings or natural regeneration where local rust resistance is sufficient,
- Forest/District maps showing locations of plus trees and elite trees are essential to developing a plan to protect them from wildland fire.
- **The Wildland Fire Decision Support System (WFDSS**) should include locations of plus and elite trees or specific areas needing special protection from wildland fire. This is

essential to developing a plan to protect important trees and sites from wildland fire, especially as fire severity and frequency increase over time.

E. <u>Proactive intervention approaches</u>.

In areas/communities where infection by *Cronartium ribicola* is at low levels or the pathogen has not yet invaded, management actions can be implemented to develop whitebark pine resilience to future impacts (Schoettle and Sniezko 2007). All ten management actions that incorporate the four basic principles (conserve genetic diversity, promote rust resistance, save seed sources, and employ restoration treatments) should be incorporated into a conservation plan for these areas.

- Healthy seed trees should be selected for resistance screening, and the distribution of resistance on the landscape should be determined and then utilized.
- Competing vegetation should be removed by prescribed fire or silvicultural thinning to reduce successional processes and encourage natural regeneration especially where genetic resistance to WPBR is highest.
- Planting resistant seedlings under good growing conditions will enhance the frequency of natural genetic resistance and provide resilience against white pine blister rust, diversify age structure, and help maintain a viable population size.
- Ensuring high levels of genetic diversity are present may help mitigate climate change effects.
- Seed collections from individual trees are important to archive genetic diversity. After results are obtained from genetic resistance testing, additional seeds should be collected from highly rust-susceptible trees and stored to serve as controls for future resistance screening and field trials.
- Planting plans should include appropriate sites that would provide some mitigation for climate change (see above).
- Ideally, forests in general should be managed at a landscape scale to reduce MPB risk. By managing other hosts, MPB impacts on whitebark pine may be reduced. Treatments at a stand level, such as daylighting and thinning, may increase resilience to MBP.

IV. <u>Surveying and Monitoring</u>

A. <u>Health and stand condition status and trends</u>

Surveys or plot networks are fundamental for monitoring management actions outlined on P. 1 but are equally as essential for assessing stand conditions as part of planning management activities. **One-time surveys have been conducted in many areas, and long-term monitoring plots and networks have been established in several regions. These efforts have provided essential information on whitebark pine health status. See Tomback et al. (2005) and Greater Yellowstone Whitebark Pine Monitoring Working**

Group (2011) for detailed examples of monitoring protocols. Continued monitoring, however, can only be justified as part of the development and implementation of a restoration plan, especially as whitebark pine health status declines. The following recommendations are in the context of developing and implementing an appropriate survey protocol.

- Work with a statistician or inventory and monitoring expert, when possible, to design monitoring protocols.
- Use a random sampling design, with sampling units distributed throughout the local whitebark pine distribution.
- For long-term monitoring, use tagged trees.
- For rapid one-time surveys, use a point-based design.
- In areas with little or no blister rust currently, supplement random sampling with targeted sampling in areas of projected high risk, such as near streams and *Ribes* spp., for early detection of infection.
- Extensive training and experience are required for recognition of blister rust symptoms and mountain pine beetle infestation.
- Examination for evidence of beetle attack should include all areas of the tree bole. Symptoms include presence of "J"-shaped galleries beneath the bark; boring dust in bark crevices, particularly around the root collar; pitch tubes; small emergence holes; and beetles actively chewing bark (Gibson et al. 2009).
- Examination for blister rust infection should include all sides of the tree and canopy; and, 10 x binoculars should be used to search for symptoms if areas of the tree are not clearly visible with the naked eye. Presence of sporulating cankers **confirm** active blister rust infection. In addition, if at least three of the following five related symptoms are present, there is good indication of infection: resin weeping, branch flagging, rodent bark stripping, roughened bark, and branch or stem swelling (Hoff 1992, Hunt and Meagher 1992).
- In addition to random sampling, monitoring should include periodic examination of plus and elite trees for blister rust infection, possibly signifying changes in rust virulence or intensity and the need to find resistant phenotypes that are more durable. Since elite trees have been rated based on resistance in their progeny, they become valuable sentinels (Sniezko and Koch 2017).

B. <u>Monitoring and adaptive management strategies</u>

1. <u>Integrating monitoring into project planning and management.</u>

For monitoring to be effective for restoration and adaptive management, the monitoring plan must be developed in concert with project planning. The effectiveness of a restoration project cannot be monitored unless the project is designed with clear and measurable management objectives. **Best practice is for each objective to include not only a general description of what the treatment is intended to accomplish, but also**

specific measurable attributes related to the objective, the amount of change desired (e.g., 40% reduction in basal area of competing conifers), and a specified timeframe (e.g., 5 years) in which the objectives are anticipated to be met. If management objectives include these details, it will be possible to evaluate whether these objectives have been met post-treatment. <u>If restoration objectives are not met within an alloted timeframe after treatment, either the restoration treatment should be modified and repeated, or a different restoration approach should be implemented.</u>

Reasons to design a monitoring plan at the time of project planning:

1. Developing a monitoring plan requires identifying how project success will be measured. This process will help ensure that the restoration plan has **clear and measurable management objectives**. Clear objectives are needed for determining project success.
2. Some monitoring questions require **collection of baseline or pre-treatment data** (see next section), but if treatments are implemented prior to developing the monitoring plan, it will not be possible to collect pre-treatment data. Not having pre-treatment data will limit opportunities for learning about treatment efficacy and effects.
3. Evaluation of some management objectives requires **data from untreated control areas or reference areas** (see next section). *Control areas* are similar in condition to treated areas, often located in proximity to areas destined for treatment, but will not receive treatment. *Reference areas* are areas of high ecological integrity (i.e., not in need of restoration) that can be used as a benchmark for success. It is important to identify these areas as part of project planning.
4. In order to interpret monitoring data, specific **information on what happened during treatment implementation may be required**. For instance, interpreting the effects of a prescribed fire treatment requires determining which monitoring plots experienced fire and, for those that did, data on the intensity or severity of the fire. This information may be easy to collect immediately after the fire but less so with time since burning. If the monitoring objectives are not developed until after treatments are implemented, the opportunity to collect data related to treatment implementation may be lost.
5. Because monitoring requires funding, not just for data collection but also for cleaning and archiving data, data analysis, reporting, and sharing results, managers should build monitoring costs directly into total project costs. In addition to ensuring that all required data are collected, developing the monitoring plan at the project outset enables managers to obtain the **financial resources and staffing** required to complete all phases of the monitoring.

2. <u>General guiding principles for monitoring</u>

There are three general categories of monitoring that are relevant to the restoration of whitebark pine (Larson et al. 2013). Most restoration treatments have components that require all three approaches to monitoring, whether seedling planting or seed sowing, prescribed fire, or silvicultural thinning.

Implementation monitoring: Did the treatment go as planned? Implementation monitoring requires collecting data during and immediately after the treatments are deployed. The data collected are variables related to the treatment itself, such as flame length, tree mortality, crown scorch, etc., or how many seedlings were planted per acre (hectare), and what were the subsequent temperature and moisture conditions?

Efficacy monitoring: Were the project objectives met? There are several different approaches to determining whether project objectives were met, with each approach answering a different monitoring question.

- If the question is *whether a particular performance condition* (i.e., objective) *has been met* (e.g., specific basal area target for mature whitebark pine), managers need only collect data from treated sites *after* treatment. Here, the comparison is condition *after* treatment to the stated performance variables.
- If the question is *whether the site has been restored* (or the extent to which it has been restored), best practice is to sample and compare treated areas after treatment with a set of reference areas (stands with high ecological integrity).
- If the question concerns *whether stand conditions are different after treatment than they were before treatment (and what is the magnitude of change?*), it is necessary to sample the treated sites *both before and after treatment* (BACI, Osenberg et al. 2006). Importantly, efficacy monitoring cannot be used to determine if the treatment **caused** observed changes in site conditions. Measuring change over time can reveal differences, but these differences could be due to factors other than the treatment (for instance weather trends). Managers interested in determining the effects of the treatment themselves should conduct effects monitoring.

Effects monitoring: What were the effects of the treatments that were implemented, including unintended consequences (both positive and negative)? The only way to determine the extent to which the implemented treatment actually altered stand conditions is to measure both treated and control sites (sites that resemble the sites that are in need of restoration but are not treated) both before and after treatment. Although this type of monitoring is the most intensive in terms of sampling time and effort, it avoids confounding treatment effects, such as confusing reduced competition with temporal and spatial variation, such as the annual variation in precipitation and site influence on tree growth rates.

Failing to meet the objectives: If efficacy and effects monitoring reveal that project objectives were not met, managers must first determine from implementation monitoring whether the treatment was applied correctly. If treatment was applied correctly and objectives were not met, managers have two choices: 1) They must consider whether the treatment should be applied again but modified in a way likely to achieve project objectives (e.g., more severe fire), or 2) they must determine whether a different treatment approach may be indicated to achieve project objectives. This evaluation comprises the adaptive management component of restoration treatments.

Well-designed monitoring is essential not only to determine whether project objectives were met, partly met, or not met, but also to provide clarity as to the reason. This information enables managers to improve treatments and align them better to specific community characteristics.

3. <u>Frequently used restoration protocols (some suggestions)</u>

Plus tree identification and adaptive management

- Each seed zone needs a target number of plus trees (e.g., 100) for the purpose of identifying rust-resistant individuals through screening and for determining the prevalence of genetic resistance. How many plus trees are you identifying within a seed zone to start?
- What is a good target number of elite trees, i.e., genetically resistant whitebark pine determined through screening, for restoration planting and seeding that represents reasonable genetic diversity? The conservation literature suggests that the 50/500 rule may be insufficient, but it is a start.
- Of the 100 plus trees identified and then screened within your seed zone, what number show relatively high genetic resistance and could be considered elite trees for cone harvesting and orchard development?
- If you confirm fewer than 50 plus trees to be elite trees, this indicates that more plus trees should be identified and screened. Even if more than 50 elite trees are identified, this number should be increased to capture rare alleles. Please consult your U.S. Forest Service regional geneticist for additional guidance.
- We recommend the continual addition of more elite trees to the restoration program over time, as support allows.

Planting seedlings/sowing seeds: proportion of seeds sown that germinated and proportion seedlings surviving.

- Identify objectives.
- Document implementation variables (planting protocols, weather and rainfall after planting).
- Identify monitoring variables.
- Sampling: 1 yr, 5 yr, 10 yr, 20 yr.
- Random points for sampling.
- Plot type and size.
- Stratification of random points in planting area by aspect, soils, and other habitat conditions.
- Identify number of plots to be sampled through power analysis.
- Sample across entire restoration project.

Silvicultural thinning and daylighting: reducing encroachment (competition) on whitebark pine

- Identify objectives.
- Identify reference conditions if available; sample reference conditions.
- Document pre-thinning conditions by sampling for baseline comparison; use random points to generate plots.

- Document implementation variables (e.g., basal area removed, slash treatment).
- Sampling: 3 yr, 5 yr, 10 yr, 20+ yr.
- Stratify sampling by aspect, soils, forest community/understory variation.
- Random points used for sampling the thinning treatment over large areas: control and treated area.
- Establish points encompassing all area treated.
- For selected daylighting, sampling within a subset of treated areas.
- Generate plot sample sizes by power analysis.

Prescribed burning: creating burned seedbed promoting whitebark pine regeneration; reducing competition; renewing successional processes for whitebark pine establishment

- Identify primary objectives.
- Sampling: 3 yr, 5 yr, 10 yr, 20+ yr.
- Identify aspirational reference conditions if available; sample conditions.
- If comparable pre-burn forest available, use as control; sample control plots over time.
- Document pre-treatment conditions for baseline composition.
- Document implementation variables (e.g., area burned, flame height, stem scorch).
- Stratify sampling by burn severity, aspect, soil type, pre-burn forest composition.
- Generate plot sample sizes by power analysis.

V. Acknowledgments

A Best Management Practices teleconference workshop was organized collaboratively by the Whitebark Pine Ecosystem Foundation, American Forests, and the Washington Office of the U.S. Forest Service as part of the National Whitebark Pine Restoration Plan. It was held on August 31, 2017, based at the U.S. Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory. We thank the following scientists and managers for their participation: Andy Bower (USFS), Emily Guiberson (BLM), Melissa Jenkins (USFS), Ellen Jungck (USFS), Sandra Kegley (USFS), Jodi Krakowski (Alberta government), Mary Frances Mahalovich (USFS), Rob Mangold (USFS, retired), Michael Murray (BC Forestry), Amy Nicholas US F&WS), Anna Schoettle (USFS), and Richard Sniezko (USFS). The workshop was hosted by Diana Tomback (Whitebark Pine Ecosystem Foundation and University of Colorado Denver), Julee Shamhart (Whitebark Pine Ecosystem Foundation), Eric Sprague (American Forests), and Bob Keane (U.S. Forest Service). Cara Nelson (University of Montana) and Elizabeth Pansing (University of Colorado Denver) provided information on additional topics during later revision. Support for the National Whitebark Pine Restoration Plan was provided by Washington Office of the U.S. Forest Service, National Forest System and Forest Health Protection. We thank Leslie Weldon, Rick Cooksey, Chris French, David Gwaze, Bruce Moltzan, John Crockett, Allan Rowley, and Eric Davis of the Washington Office, U.S. Forest Service.

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