Strategies, Tools, and Challenges for Sustaining and Restoring High Elevation Five-Needle White Pine Forests in Western North America

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Abstract—Many ecologically important, five-needle white pine forests that historically dominated the high elevation landscapes of western North America are now being heavily impacted by mountain pine beetle (*Dendroctonus* spp.) outbreaks, the exotic disease white pine blister rust (WPBR), and altered high elevation fire regimes. Management intervention using specially designed strategic treatments will be needed to conserve these keystone species. The goal of this intervention is to promote self-sustaining five-needle white pine ecosystems that have both resilience to disturbances and genetic resistance to white pine blister rust. Many tools and methods are available for land managers. In this paper we outline important steps for implementation of restoration treatments in declining high elevation white pine stands and discuss a number of proactive treatments in threatened ecosystems to mitigate adverse impacts of rust, beetles, and lack of fire. These steps for restoration include (1) create a strategy for restoration across multiple scales, (2) develop materials and techniques for conducting restoration treatments, such as seed collections and rust resistance assessments of the genetic material, (3) prioritize stands or landscapes by integrating the strategy with other management issues, administrative barriers, climate change mitigation, and other local concerns, (4) implement silvicultural cuttings and prescribed fire according to landscape and stand level strategies, (5) conduct activities and assessments to enhance and ensure restoration treatments are effective including planting rust-resistant pine seedlings and protecting valuable seed-sources, and finally (6) monitor treated landscape and stands for effects and adjust and modify future treatment designs accordingly. Examples from whitebark pine ecosystems in the northern Rocky Mountains will be presented to demonstrate this process. For those high elevation white pine ecosystems that are threatened by white pine blister rust or mountain pine beetle, there are actions that can be taken proactively to gain necessary information to evaluate risk and prepare landscapes for invasion to mitigate future impacts. The proactive strategy includes: (1) educate and engage the public and managers to shift from crisis management to management for resiliency, (2) conserve genetic diversity from native populations before they are impacted by WPBR or other stresses, (3) conduct research on patterns, processes and responses of native ecosystems to provide process level understanding of ecosystem behavior and (4) develop and conduct appropriate management activities to increase the resiliency of high elevation five-needle pine ecosystems to prepare them for change. Whether it is restoring impacted landscapes or interventions to mitigate the development of impacts on threatened landscapes, there are two important factors that will govern the success of these species even with comprehensive and effective rangewide strategies: (1) the magnitude of resources available over time to conduct restoration efforts, and (2) the commitment of natural resource agencies to conduct restoration activities over the long term, most likely for many decades to centuries.

Introduction

Many high elevation five-needle pines (HEFNP) forests in western North America are declining because of complex interactions across multiple factors. Whitebark pine (*Pinus albicaulis*) and limber pine (*Pinus flexilis*) are declining across many parts of their range in the United States and Canada because of the infestations of the exotic white pine blister rust (WPBR; *Cronartium ribicola*) and outbreaks of the native mountain pine beetle (*Dendroctonus ponderosae*), which are further exacerbated by the continued policies of fire exclusion and emerging changes in climate (Arno 1986; Koteen 1999; Kendall and Keane 2001; McKenney and others 2007). The other HEFNPs—foxtail pine (*P. balfouriana*), great basin bristlecone pine (*P. longaeva*), southwestern white pine (*P. strobiformis*), and Rocky Mountain (RM) bristlecone pine (*P. aristata*)—have not yet experienced the major declines observed in northern distributions of limber and whitebark pines, but they are also in imminent danger from blister rust and beetles (see Tomback and others, this proceedings, The Magnificent High-Elevation Five-Needle White Pines). These HEFNP upper subalpine and treeline forests are ecologically invaluable to landscape dynamics and biodiversity so restoring these ecosystems is important for ecological sustainability and society (Tomback and others 2001a; Tomback and others, this proceedings, The Magnificent High-Elevation Five-Needle White Pines). Management intervention is urgently needed in some cases to restore the declining keystone species (Schwandt 2006; Aubry and others 2008) and sustain the remaining healthy ones (Schoettle and Sniezko 2007).

In this paper we will present two separate but overlapping approaches for guiding restoration in HEFNP landscapes: (1) important steps for implementation of restoration activities in declining landscapes and stands, and (2) steps for implementing proactive intervention to provide opportunities for early treatments in threatened ecosystems to mitigate future impacts. The goal of both approaches is to promote self-sustaining five-needle pine ecosystems in the presence of the WPBR using those strategies, tools and methods that are available for land managers.

The steps for implementation of successful restoration in declining HEFNP ecosystems are:

In: Keane, Robert E.; Tomback, Diana F.; Murray, Michael P.; and Smith, Cyndi M., eds. 2011. **The future of high-elevation, five-needle white pines in Western North America: Proceedings of the High Five Symposium.** 28-30 June 2010; Missoula, MT. Proceedings RMRS-P-63. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 376 p. Online at http://www.fs.fed.us/rm/pubs/rmrs_p063.html

- *Develop a strategy.* Craft a comprehensive strategy for restoring HEFNP that spans multiple scales of time, space, and organizational structure;
- *Develop resources for restoration.* The success of a coordinated restoration effort will depend on diverse sets of materials and methods for conducting restoration treatments, such as seed collections, rust resistance assessments of the genetic material, development of planting guidelines, and cone collection techniques;
- *Prioritize areas for restoration.* A multi-scale prioritization scheme must be devised so that regions, landscapes, and stands can be identified for restoration by integrating the strategy mentioned above with management conflicts and issues, administrative barriers, climate change impacts, and the myriad of local to national issues;
- *Implement restorative treatments.* Passive and active treatments, such as wildland fire use, silvicultural cuttings and prescribed fire, must be implemented across the landscape following the strategy mentioned above;
- *Conduct restoration enhancement activities.* There are many management activities that can be conducted to ensure effective restoration treatments, including planting rust-resistant pine seedlings and protecting valuable seed-sources; and finally
- *Monitor treatments.* Since research funds for studying these important HEFNP ecosystems are scarce, it is incumbent on forest managers, with extensive help from the research community, to monitor treated stands and landscapes for adverse effects so that future activities can be adjusted and modified to improve overall efficacy.

We will use examples from whitebark pine and limber pine ecosystems in the northern Rocky Mountains to demonstrate this process.

Activities in the HEFNP ecosystems that have not yet been impacted can be used to promote resiliency and sustainability. These steps include:

- *Educate and engage.* Increase awareness of the threats to the HEFNP ecosystems and facilitate a shift from crisis management to managing for sustained resilience.
- *Gene conservation.* Take advantage of the intact healthy ecosystems to assess and capture the genetic diversity for gene conservation, research and future management activities.
- *Research patterns, processes and responses.* Gain information on natural disturbances and management responses to provide valuable process-level information to evaluate future impacts and treatment effectiveness as well as parameterize predictive models. Assess geographic patterns of natural frequencies of resistance mechanisms to white pine blister rust.
- *Prepare the landscape for change.* Develop and implement interventions to increase adaptive capacity, mitigate ecosystem impacts of tree mortality, and accelerate the increase in frequency of rust resistance.

The proactive strategy will be outlined with examples from the southern Rockies.

There are two important factors that will govern the success of restoring HEFNP forests: (1) the magnitude and dependability of resources available over time to conduct restoration efforts, and (2) the commitment of natural resource agencies to conduct restoration activities over the long term, most likely for many decades to centuries. These resources can be in the form of funding, personnel, collaborative planning efforts, or public support. Because HEFNP ecosystems have little value as timber species, it is doubtful that any restoration treatment or activity will generate appreciable incomes, so the success of any restoration strategy depends on the effective and strategic allocation of limited government resources across multiple spatial scales. Government agencies must have a long-term commitment to HEFNP restoration because it takes a long time for high elevation ecosystems to respond to the effects of most restoration treatments so it may take decades to evaluate treatment success or failure (Agee and Smith 1984). Moreover, climate change may prolong and exacerbate fire, WPBR, and mountain pine beetle effects for many years so it is important that agencies commit to long-term restoration strategies now to prevent local extirpation later.

Restoration Strategy for Declining Ecosystems

Design a Strategy

The success of HEFNP restoration attempts will be greatly enhanced if a coordinated strategy is developed that integrates the latest scientific findings into a comprehensive plan for species conservation across multiple scales of time, space, and organization. Since more than 90 percent of whitebark pine forests, and most other HEFNP forests, exist on public lands managed by the U.S. Forest Service and National Park Service in the U.S. and by provincial and federal agencies in Canada (Keane 2000; Tomback and Achuff 2010), government land management agencies play key roles in ensuring the survival of these ecologically valuable tree species. It is important that these government agencies employ a coordinated plan for species restoration to ensure that there are no conflicting actions that could result in further declines of HEFNP species. An inter-agency, and even trans-boundary restoration strategy, must be crafted to emphasize infrastructure, expertise, and agency strengths for implementation, and to make efficient use of scarce resources in these under-funded HEFNP ecosystems. This integrated strategy can result in successful, cost-effective efforts for restoring declining pine species across its entire range.

Several U.S. Forest Service Regions have developed various management options and strategies for HEFNPs (Mahalovich and Dickerson 2004; Burns and others 2008; Aubry and others 2008; Conklin and others 2009), and a general range-wide strategy is being developed for whitebark pine (Keane and others 2012 [in press]) . The rangewide

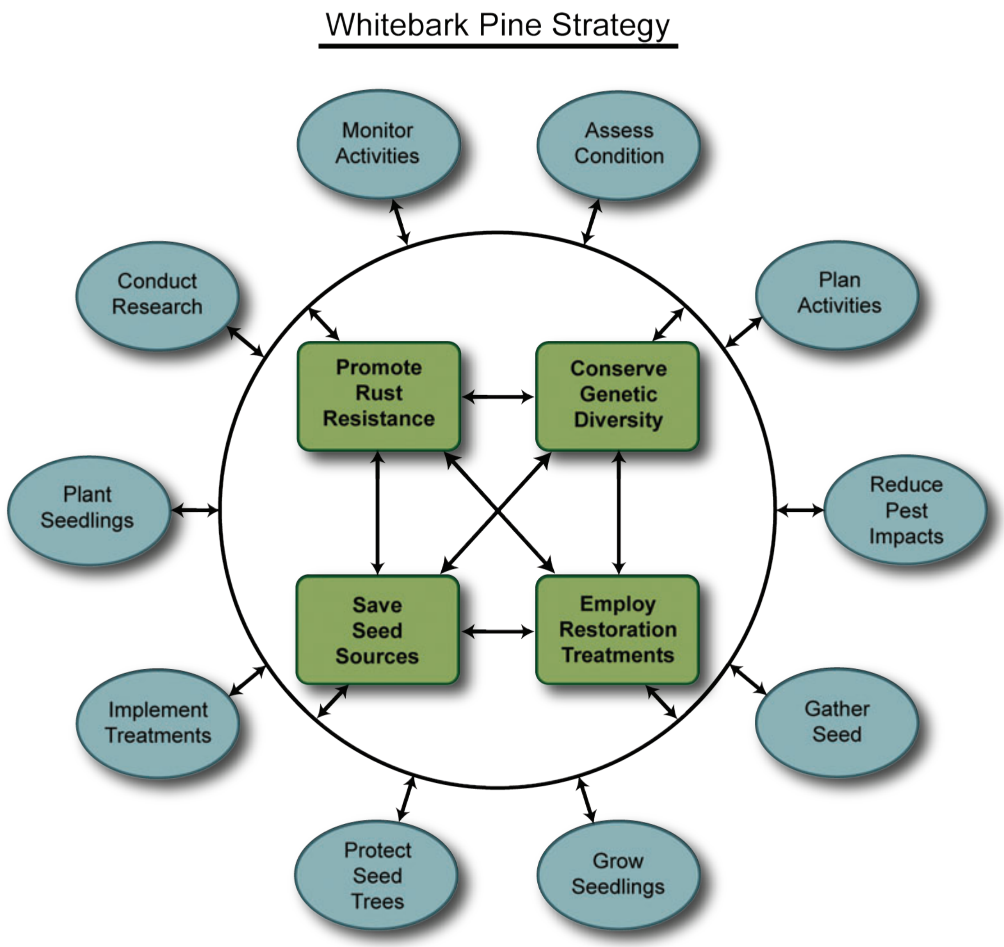

Figure 1. Important elements of the rangewide restoration strategy developed by Keane and others (2012[in press]).

restoration strategy for whitebark pine features coordinated efforts between agencies in both the U.S. and Canada and consists of a general set of four principles to guide the design, planning, and implementation of restoration activities (fig. 1): (1) promote rust resistance, (2) conserve genetic diversity, (3) save seed sources, and (4) employ restoration treatments. These guiding principles form the foundation for implementing the restoration strategy using a set of possible actions which include assess condition, gather seed, test the seed for genetic rust resistance, grow seedlings, protect seed sources, implement restoration treatments, plant rust-resistant seedlings, monitor activities, and support research. The strategy is organized by six spatial scales of analysis and organization: (1) rangewide, (2) regional (National Forests or Provincial Regions, for example), (3) forest (National Forest, National Park, and Canadian Forest District), (4) landscape (watershed, landform), (5) stand, and (6) tree. This general strategy can be used as a template for crafting strategies for all HEFNP species.

An effective strategy must be (1) implemented across all levels of organization, (2) fully integrated in planning, protection, and treatment activities across many land management agencies at various scales of management, (3) focused on specific local areas rather than implemented at low intensity across the entire species range, and (4) based on the best scientific information available to better predict and evaluate intervention outcomes. Thus, restoration efforts for high elevation pine forests need not be implemented across an entire National Forest or National Park; the most successful programs are probably those that concentrate limited restoration resources on high priority sites where potential restoration success is high.

Develop Resources for Restoration

There are a number of activities that can be done locally, regionally, or rangewide to provide the materials and methods needed to properly initiate and implement restoration treatments. Developing, collecting, and maintaining the comprehensive data that provide context for restoration actions is an important task so that the necessary information can be used to evaluate risk and prepare landscapes for invasion so future adverse impacts will be mitigated (Schoettle and Sniezko 2007). Mapping the distribution of the species, threats to the species, spatial context (land ownership, wilderness, and roads, for example), forest structure and developmental stages, and forest condition (level of mortality and their causes) at multiple scales is an important first step (Aubry and others 2008; Burns and others 2008; Keane and others 2012[in press]). Standard GIS spatial analysis techniques can be used on available digital maps describing HEFNP ecology and management issues to provide the

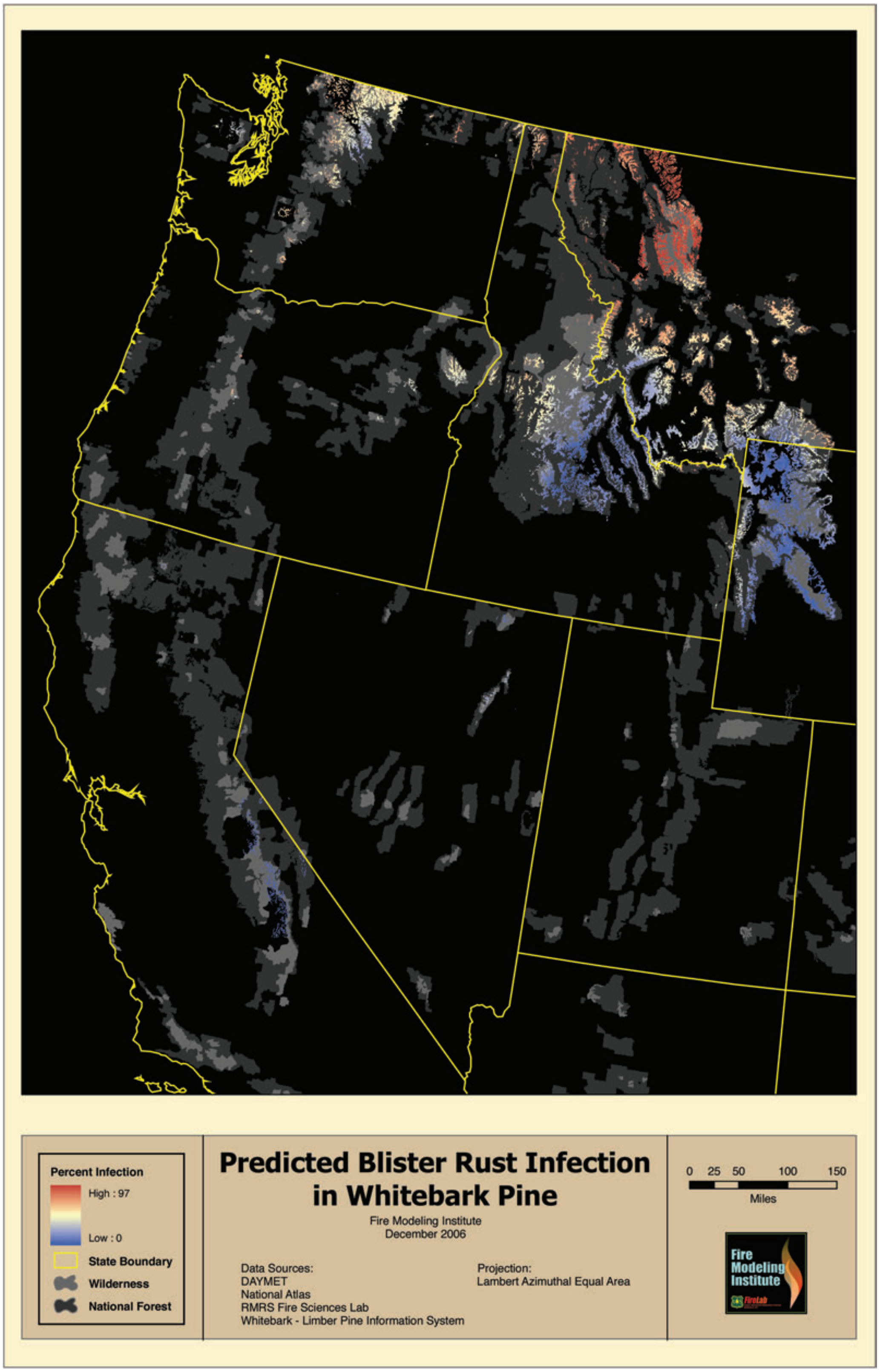

Figure 2. Digital GIS map showing modeled rust infection rates in whitebark pine across its range in the United States created using bioclimatic modeling.

critical spatial information needed for many restoration efforts. For example, gene conservation and seed collection guidelines can be geographically stratified by species distribution, biophysical settings, and ecological conditions. Risk maps of WPBR infection levels are useful to identify areas to monitor, collect seeds, and assess for intervention prioritization (fig. 2). Integrated research projects should address restoration effects and consequences such as assessing regeneration requirements and capabilities, testing silvicultural treatments to promote regeneration, and characterizing WPBR resistance frequencies, mechanisms and distributions across the landscapes.

The design of both a seed conservation plan and a blister rust screening process for creating rust resistent seeds and seedlings for restoration efforts are perhaps the two most important resources that can improve success and efficacy of restoration activities. Assessing the natural frequency of rust resistance in populations that are under consideration for treatment and developing a gene conservation plan to capture this resistance are essential for accurate predictions of restoration outcomes. Development of a regional cone collection program represents a significant step to ensure sufficient seeds are available for the growing and planting of rust-resistant seedlings in post-burn or post-treatment areas (Mahalovich 2000). U.S. Forest Service Regions 1, 2, 4 and 6 have developed an extensive whitebark pine program that includes collecting seed, screening rust resistance, initiating common gardens studies, and modifying seed zones (Mahalovich 2000, Aubry and others 2008). Stands with high infection levels are a high priority for cone collections from phenotypically resistant trees (Hoff and others 2001). Trees that appear healthy in high infection level areas are more likely to have genetic, and therefore heritable, rust-resistances and are less likely to be "escapes". However, rust-resistant seed trees can also be indentified in stands not yet infected by the WPBR (Schoettle and others 2009), so restricting collections to high WPBR hazard locations is probably not desirable if the goal is to capture high genetic diversity (Schoettle and Sniezko 2007). Since it is important to maintain genetic diversity in HEFNP ecosystems across their entire range, seeds should be collected from a variety of sources instead of continually harvesting cones from the same trees each year. It is also critical that the seeds harvested from HEFNP species be screened for blister rust-resistance to identify the level of blister rust resistance in the parent trees and estimate the frequency of resistance in the populations.

Developing techniques and approaches that will assist or enhance restoration efforts are also critical for improving restoration efficiency of HEFNP ecosystems. One essential task is collecting cones for seed for artificial regeneration. The cost of collecting whitebark pine seed is high because cones must be caged to prevent squirrels and nutcrackers from harvesting the seed, which requires climbing trees in the early summer to install the cages, and then climbing the trees again in late summer to harvest the caged cones. Comprehensive cone caging and collection techniques, such as the use of tree tongs (Ward and others 2006; Murray 2007), are greatly needed to reduce collection costs on the bird-dispersed HEFNPs (fig. 3). Tree climbing damages valuable rust-resistant trees so the development of any technique that reduces branch and bole damage, while also being cost effective, would ensure continued survival of the collection trees.

There also needs to be continued improvements in nursery techniques to reduce the cost of growing seedlings. There have been impressive gains in techniques for growing seedlings that have improved survival, reduced costs, and conserved valuable seed. However, the cost of growing whitebark pine seedlings is still high, making effective large-scale restoration plantings difficult with limited funding. Nursery techniques for growing whitebark, limber and RM bristlecone pines have been established, but there needs to be more work for the other HEFNPs. Progress has been made for planting guidelines for whitebark pine (Scott and McCaughey 2006; Izlar 2007; McCaughey and others 2009) and studies are underway for limber pine (Casper and others, these proceedings). The new guidelines have resulted in great improvements in whitebark pine seeding survival (Izlar 2007). However, planting techniques for the other HEFNPs are still needed.

Figure 3. Tree tongs used to put cages on whitebark pine cones to protect against Clark's nutcracker and rodent damage

Education and training programs for both the public and government agency personnel are critical for planning and implementing successful HEFNP restoration programs. Current scientific knowledge and research findings must be synthesized into formats that are easily understood by both agency staff and the public at large. Overview documents, such as Samman and others (2003) and Schwandt (2006) are useful, as are regional management plans (Aubry and others 2008; Burns and others 2008; Conklin and others 2009; Mahalovich and Dickerson 2004). The more the public and agency people know about HEFNP ecology and restoration, the easier it will be to establish a multi-scale restoration plan across the entire range of a species.

Prioritize Areas for Restoration

A first step towards implementing a comprehensive range-wide restoration effort is to identify those areas that, with management, have the greatest likelihood of success to support sustainable HEFNP populations and provide ecosystem services at the stand, landscapes, and regional levels Even in regions where pine losses are not yet great, such as the southern Rocky Mountains, the Sierra Nevada and interior Great Basin ranges, proactive strategies (see Schoettle and Sniezko 2007) may help prevent the severe declines experienced elsewhere (see proactive strategy section below).

Prioritizing landscapes for restoration requires comprehensive assessments of those factors that influence the decline of high elevation pines and those that function as barriers or facilitators of restoration activities. Assessments performed at this scale may be for several purposes: (1) to determine overall health and condition of the landscape or stand, (2) to inform design of restoration treatments, (3) to provide a context for assessing restoration goals (land ownership, accessibility for example), (4) to identify issues that could influence restoration efforts (grizzly bears, wilderness, for example), (5) to describe disturbance regimes that can be used to guide restoration design, and (6) to identify areas that provide ecosystems services (watershed protection, recreation). Collectively, these factors and others can be used to rank areas for restoration priority. For example, landscapes with stands that are experiencing high levels of pine mortality due to WPBR, beetles or succession and that are greater than 12-15 km (mean distance to expect nutcrackers to reestablish a whitebark stand) from a rust-resistant pine seed source might be a high priority for treatment when further decline of the stand might result in local extirpation.

Assessments at the stand level almost always involve some inventory or monitoring to provide the data that guides restoration planning, design, and implementation. There are many inventory and monitoring systems that can be used to sample stand attributes including FIREMON (Lutes and others 2006), FSVEG, and FFI (Benson and others 2005). It is critical that any inventory or monitoring effort include an assessment of those factors that are contributing to HEFNP decline or that are putting the populations at risk , such as rust infection incidence, rust-caused canopy kill, mountain pine beetle-caused mortality, pine regeneration potential, shade tolerant tree species density, and ground cover. The Whitebark Pine Ecosystem Foundation (www.whitebarkfound.org) methods for surveying whitebark pine are focused on health assessment of stands and they implicitly allow for comparisons among stands and areas. These methods are being adapted for use in limber pine stands (C. Smith, personal communications) and have already been modified for use in other HEFNP stands (for example, Burns 2006). For whitebark pine and limber pine, a database of forest health assessments has been established to facilitate the use of existing data and assessing changes in condition over time (WLIS; Lockman and Denitto 2007).

There are a multitude of variables that can be used to describe stand conditions for assessing restoration concerns and designing appropriate management treatments. Disturbance history can provide guidance to determine the frequency, intensity, and severity of restoration treatments that emulate historical disturbance regimes. Fire history can be assessed by visual evidence within the stand, such as fire scars on trees, age class structure of the stand, and charcoal in the soil. Successional status and current stand condition can be determined from the tree density by size class and species. Has the time since last fire has been excessively long (greater than one fire rotation) or past the historical fire-free interval, especially on seral whitebark pine sites? Wildfires can be used as restoration tools. If the stand burned within the last century, then the use of fire as a restoration tool would not be an option, but planting of resistant seedlings may be recommended if the post-fire recovery was hampered by blister rust or limited by inadequate seed supply and dispersal. Although mountain pine beetles are endemic to many HEFNP ecosystems, it is important that their outbreak levels be quantified to maximize the success of restoration treatments; many treatments can be rendered ineffective if they are followed by mountain pine beetle infestations. Some treatments, such as thinning, actually attract mountain pine beetles, which can then kill the pine that has been favored by treatments (Baker and Six 2001).

The degree of successional advancement is also an important prioritization criterion for some of the HEFNPs, and since successional dynamics differ by biophysical environment, it is important that successional condition be stratified by site type (Keane 2001). Succession is one of the three major factors causing the reduced whitebark pine prevalence throughout its range (Tomback and others 2001; Tomback and others, these proceedings, The Magnificent High-Elevation Five-Needle white Pines). For example, whitebark pine occurs on two general community types: climax and seral types. Climax whitebark pine stands are mostly dominated by whitebark pine, depending on the harshness of the site, and whitebark pine is the indicated climax species, so succession to more shade tolerant tree species is not a concern. In stands where whitebark is seral to more shade tolerant conifers (seral site types), the absence of disturbance often leads to a loss of HEFNP seral communities. Treating stands earlier in the successional process would reduce loss of the whitebark pine component, possibly increase cone production, and decrease the likelihood that the stand will support a crown fire that would kill cone-bearing whitebark. For whitebark pine, any stand with greater than 50 percent basal area in subalpine fir and Engelmann spruce might have a high priority for treatment, especially if the landscape is composed of greater than 20 percent subalpine fir dominated stands by area (Keane and others 2012[in press]). Stands with high densities of subalpine fir in the understory (greater than 1,000 trees acre-1) should also be prioritized for treatment.

Other management issues could be included as criteria for prioritization. The grizzly bear is a politically important species that takes whitebark seeds from squirrel middens. In general, squirrels and their middens are more abundant in stands with high numbers of mixed conifer species that produce more constant supplies of squirrel food compared to pure whitebark stands that produce highly variable seed crops (McKinney and Fiedler 2010). Midden size and probability of occupancy decrease with increasing elevation. Grizzly bears suffer from anything that removes cone-producing whitebark pine, reduces squirrel densities, or reduces the size of squirrel middens (Mattson and others 2001). Restoration prioritization for whitebark should emphasize data layers that integrate grizzly population levels and squirrel habitat (mixed conifer stands). Bears also avoid areas with on-going human activity, such as stand preparation for restoration activities. Management of whitebark pine forests for grizzly bears could emphasize maintaining large secure areas of diverse habitat types supporting stable numbers of whitebark pine trees and squirrels.

Areas that have high value for cultural, historic, recreational, and ecosystem services reasons may also be emphasized for restoration or intervention. Headwaters for many watersheds are stabilized by HEFNP forests; these areas could be prioritized for treatment if a change in hydrology could threaten water yield, water quality, geomorphology, aquatic organisms, or slope stability. Areas where the HEFNP forests are an integral aspect of Native American cultures should also be high priority as well as those areas of high esthetic value for recreation. Key ecological areas that connect other areas via gene flow or that may encompass a large isolated population may also be prioritized for intervention to help conserve the species' genetic structure.

Implement Restoration Treatments

The primary goal of most restorations treatments is to promote regeneration and establishment of the HEFNPs, and because these species are early seral, it is important to understand the disturbance ecology of the landscapes prioritized for treatment. Wildland fire is the keystone disturbance that shaped many HEFNP landscapes, so most cases, restoration treatments can be designed at the landscape- and stand-level to emulate fire's effects (Keane and Arno 2001; Perera and others 2004). While prescribed fire seems the obvious tool for mimicking historical fire effects at the stand level, mechanical cutting treatments can also be effective in accessible areas; properly designed silvicultural thinnings can be designed to emulate the effect of stand-replacement, mixed severity and non-lethal surface fires in whitebark stands (Keane and Arno 2001; Keane and Parsons 2010b). Treatment unit sizes and shapes should be similar to the patterns left by past fires and need to reflect the amount of available pine seed source in surrounding stands and the mode of seed dispersal for the target HEFNP (Coop and Schoettle 2009; Keane and Parsons 2010a). Burn patches of 5 to 50 acres were found to be attractive to Clark's nutcrackers for whitebark pine establishment (Norment 1991). Treatments that create large areas for whitebark pine regeneration should be avoided if there is little seed available for caching unless the planting rust-resistant seedlings is planned (McKinney 2004).

The efficacy of the treatment to stimulate natural HEFNP regeneration will also depend on local climatic, topography and biotic factors. Whitebark pine and limber pine are regenerated almost exclusively from Clark's nutcracker seed caches, so treatments should be designed to emphasize those site conditions that attract Clark's nutcrackers to cache their seed so unclaimed seed can germinate and grow into viable seed-producing trees. Caching habitat for the Clark's nutcracker is likely recently burned areas because it appears that the birds readily cache in recent burns, but research here is incomplete. What is more important is that the seedlings germinated from unclaimed cached seed can grow in the absence of competition which ensures the continued survival and growth of whitebark pine seedlings. Whitebark pine and limber pine seedling survival depends on many factors but the lack of competition, exposure to open sky, and protected microsite conditions that nutcrackers select appear to be the most important (Coop and Schoettle 2009; Izlar 2007; McCaughey and others 2009).

For whitebark pine forests, perhaps the most efficient tool for landscape level restoration efforts are planned wildfires (wildland fire use or prescribed natural fires: lightning-started fires that are allowed to burn under acceptable weather and site conditions as specified in a fire plan) and unplanned wildfires (Black 2004), assuming sufficient seed sources remain unburned. The aggressive use of planned wildfires has the potential to be an efficient, economical, and ecologically viable method of restoring whitebark pine in many areas, especially wilderness. Landscapes where wildfires might be contra-indicated are those with few whitebark pine seed sources both near and distant, and low frequency of rust resistance in the populations. In these places, we recommend the protection of mature, cone-producing trees and augmenting the population and the frequency of resistance with planting rust-resistant seedlings (see next section). Otherwise, most wildfires will probably improve whitebark pine's status and health if the fires are carefully monitored to minimize fire-caused mortality of potentially rust-resistant trees. However, it is highly recommend that burned areas in landscapes with high blister rust infection (greater than 50 percent) and mortality (greater than 20 percent) be planted with apparent rust resistance pine seedlings (Keane and Parsons 2010a; Keane and Parsons 2010b).

Large wildfires may be important for HEFNP restoration in those areas of their range that historically experienced extensive fires in a given year, such as the northern Rocky Mountains of the U.S. Conventional wisdom is that wildfires today may burn larger areas more severely than the past because of the buildup of fuel from fire suppression efforts (Van Wagtendonk 1985, Ferry and others 1995), but recent research has found that these large fires actually leave a mosaic of intensities and severities that are similar to historical conditions (Keane and others 2008). Land and fire managers should view wildfires as a possible mechanism for restoring high elevation systems and use ecologically based decision support tools to decide whether or not to let wildfires create potential restoration sites for HEFNPs. Moreover, wildfire rehabilitation teams should evaluate the levels of cone production, WPBR infection, and beetle mortality, along with levels of rust resistance on these landscapes to assess if planting putative rust-resistant whitebark pine is needed.

There are basically two major types of stand-level restoration treatments: prescribed burning and mechanical cuttings. Other treatments can be used to augment or complement the two major treatment types. Most restoration treatments are designed to reduce or eliminate competing species and increase the regeneration opportunities for blister rust-resistant HEFNP seedlings. Again, the primary objectives of these treatments are to promote self-sustaining five-needle pine ecosystems that have resilience to disturbances and genetic resistance to white pine blister rust. It is also important to emulate some historical disturbance process, mainly wildland fire, and to facilitate whitebark regeneration and cone production by creating optimum nutcracker caching habitat, protecting seed sources, and planting rust-resistant seedlings (see next section). Keane and Parsons (2010a; 2010b) summarized results of a 15 year whitebark pine restoration study by treatment across five diverse sites that can be use for evaluating, designing, and implementing HEFNP treatments.

Mechanical cuttings

Mechanical cuttings include treatments that manipulate the stand by cutting trees (fig. 4). Traditional silviculture may have limited effectiveness in these high mountain stands because of the severity of the site, the unique autecology of HEFNPs, and bird-mediated seed dispersal of some of the HEFNPs (Keane and Arno 2000). Silvicultural strategies that are specifically tailored to individual stands are needed to address restoration concerns in high elevation pine forests (Waring and O'Hara 2005). In general, most cuttings should attempt to eliminate shade-tolerant tree competitors while enhancing pine regeneration and vigor. Thinnings can be used to improve the health of potential cone-producing pine, while other cuttings can be used to create fuelbeds to support prescribed burning activities. Usually, mechanical cuttings are only effective when treated stands are in close proximity to roads and are easily to work in (gentle slopes, few rocks, few wet areas, for example).

Figure 4. Cutting subalpine fir trees in a mechanical restoration treatment in a whitebark pine forest.

Six types of mechanical cuttings are currently being used in restoration treatments for whitebark pine. Keane and Parsons (2010a) created nutcracker openings in successionally advanced subalpine fir stands containing healthy and dying, WPBR infected whitebark pine. These nutcracker openings were near-circular areas within which all trees except whitebark pine were cut. The size of these areas may vary, but they can be anywhere from 1-30 acres based on a study by Norment (1991). The nutcracker openings treatment also attempts to mimic patchy, mixed severity wildfires. Other cutting treatments include group selection cuts where all trees except whitebark pine are sawn down, and thinnings where all non-whitebark pine trees below a threshold diameter are cut (Chew 1990; Eggers 1990). Girdling subalpine fir trees has also been attempted on some restoration efforts because it is a cheap, rapid means of killing competing subalpine fir (Jenkins 2005). However, to be effective, the girdling has to be done below the lowest live branches or those branches can form new boles. Girdling also leaves a large portion of the fuel on the site which could foster high severity wildfires that could kill those pine trees being restored. Daylighting (cutting of shade-tolerant competing species in a circle around whitebark pine trees) has been gaining favor among managers because it is cheap and easy, but there is little research on its effectiveness. One last cutting is a fuel augmentation or fuel enhancement treatment where subalpine fir trees are directionally felled to increase fuel loadings and fuelbed contagion (Keane and Arno 1996; Keane and Arno 2001). Keane and Parsons (2010a) found this treatment highly effective for facilitating prescribed burning. It is important to reduce or remove the cutting slash from a treated site to (1) allow nutcrackers full access to the ground for caching (Keane and Parsons 2010b), (2) reduce potential mortality from *Ips* spp. beetles (Baker and Six 2001), and (3) reduce the severity of future unplanned wildfires (Keane and Arno 2000). This can be done by piling the slash and then burning the piles, whole tree skidding to a landing which removes the branches from the site, or augmenting the cutting with a prescribed fire.

To shift the advantage to shade-intolerant HEFNPs, elimination of the shade-tolerant competitors is the most important requirement of any cutting prescription, and the competing cone-bearing trees should be eliminated first. In whitebark pine forests, subalpine fir has frequent large cone crops with numerous seeds that can often create dense stands. The most effective cutting treatments will be those that eliminate the most subalpine fir trees, starting with the cone-bearing trees. The presence of residual seedling and sapling subalpine fir after a cutting treatment can shorten the life span of that treatment and render it ineffective after a short time. The implementation of a prescribed burn after a cutting treatment can kill the understory subalpine fir and make the treatment effective for longer.

Prescribed burning

Prescribed burning may be the most desirable treatment because it best emulates wildland fire regimes (fig. 5), but it is also the most difficult and riskiest treatment to implement. Prescribed burns can be implemented at three intensities to mimic the three types of fire regimes common in whitebark pine and other HEFNPs forests: non-lethal surface fires, mixed severity burns, and stand-replacement fires (Brown and Schoettle 2009; Murray and others 1995; Siderius and Murray 2005; Walsh 2005). The primary objective of low intensity prescribed fires is to kill competing overstory and perhaps understory, and to preserve the HEFNP component. Moderate intensity prescribed burns can be used to mimic mixed severity fires where passive crown fire behavior is common in dense thickets which burn patches of variable size depending on wind, canopy contagion, and fuel moisture conditions. A high intensity prescribed burn, while difficult to apply and control is important for the bird-dispersed HEFNP species because it creates patches that are so large that seeds from competitors are unable to disperse into the center of the burn, allowing HEFNP regeneration decades of competition-free growth after germinated seeds are cached by nutcrackers.

A fuel enhancement cutting implemented one year prior to a prescribed burn is a good way to ensure that burn objectives are fully realized (Keane and Parsons 2010a). The addition of cured slash to discontinuous fuelbeds improves burn effectivness by providing additional fine fuel to (1) aid fire spread into all areas of the stand and (2) augment quickly drying fine fuel loadings so the burn can be implemented under moist conditions. Prescribed burns have a greater coverage and higher severity in stands where the fuels were enhanced (Keane and Arno 2001). Fuel enhancement is somewhat easy, cheap, and relatively quick, and it can be done by timber crews, fire crews or contractors. Keane and Parsons (2010b) also found that shrub and herbaceous fuels were much drier after the first hard frost in late summer or early autumn. This frost kills the aboveground foliage that allows the plants to take water from the soil so the entire plant structure can dry sufficiently for burning.

Conduct Restoration Enhancement Activities

There are several activities that can be implemented before or after major treatments to ensure that the restoration is successful. These activities are usually done to enhance the continued survival of seed-producing individuals within the treated area, and also to facilitate the successful regeneration of high elevation pines in disturbed areas. These activities fall into two classes: planting and protection.

Planting

As HEFNP communities continues to decline across their range, there will be fewer seeds produced and fewer still available for pine regeneration (fig. 6). Furthermore, those seeds produced in damaged stands are highly sought after by pre-dispersal seed predators, especially pine squirrels but other birds, leaving few seeds for nutcracker caching (McKinney and Tomback 2007; McKinney and others 2009). For this reason, in high rust mortality or mountain pine beetle impacted areas, there may not be sufficient seed to naturally regenerate the HEFNPs and planting rust-resistant seedlings may be the only option to regenerate the species (Keane and Parsons 2010a). In addition, if the local seed sources contain little or no heritable resistance to white pine blister rust, artificial regeneration with rust-resistant seedlings will not only increase the population size, but also augment resistance in the future pine populations (Schoettle and Sniezko 2007). If there is higher than 50 percent HEFNP mortality, it is essential that the treated areas be planted with putatively rust-resistant pine seedlings (Keane and Parsons 2010b).

It may be beneficial to plant HEFNP seedlings on a variety of site conditions with a variety of methods to refine planting guidelines to optimize survival and growth of future plantings. Some general planting guidelines were developed by the various agencies and researchers for whitebark pine (Greater Yellowstone Coordinating Committee Whitebark Pine Committee 2001; McCaughey and others 2009; Scott and McCaughey 2006) and are in development for limber pine (Casper and others, this proceedings). On the broad scale, planting should be done on a variety of sites,

Figure 5. Prescribed burning in a whitebark pine forest as part of a restoration treatment to kill competing subalpine fir trees

Figure 6. Planting whitebark pine seedlings in area burned by a fire that was allowed to burn under prescribed conditions in Glacier National Park, Montana, USA (Photo from Kate Kendall).

including the more productive seral sites. When practical, planting crews should attempt to remove non-HEFNP conifers to make planting effective in the long-term. Reduce overstory, understory, and undergrowth (grasses and shrubs) competition to increase light and improve the effective growing season and increase available moisture. Avoid planting whitebark pine in swales or frost pockets and provide shade and protection for newly planted trees to improve water utilization and to reduce light intensity and stem heating (plant by stumps or other stationary shade-providing objects). Planting sites should have some protection from heavy snow loads and drifting snow and planted trees should be widely spaced to avoid long-term inter-tree competition. Summer and fall outplanting have been successful, thereby avoiding the need for expensive snow plowing and delayed entry due to heavy spring snow loads. Whitebark pine seedlings take five to seven years before they become fully established and start significant height growth.

Direct sowing of HEFNP seed instead of planting seedlings could significantly reduce the cost and effort of regenerating sites if technologies improve. Broadcast seeding results in nearly 100 percent consumption of whitebark pine seed by rodents (McCaughey and Weaver 1990), so these seeds must be sown to reduce predation. A potential tactic may be to plant two to four seeds about 2 to 3 cm deep in one planting site with a specially designed dibble. The seeding approaches are being investigated (Smith and others, these proceedings; Schwandt, personal communication) and if successful, they will provide cost-effective methods for regenerating large high elevation burns in a short time.

Protection

Protection is an activity ensuring high value mature, cone-producing, rust-resistant HEFNP trees remain on the landscape so that seeds are available for natural regeneration and collection by managers for rust screening and restoration plantings. A common tree-level restoration activity is to protect trees from a wide variety of disturbance agents, primarily fire, beetles, and rusts. These protection activities can be done prior to treatment and just after the treatment to ensure continued pine seed production. The best trees to protect from these agents are those that have been identified as important sources for genetic and phenotypic rust-resistant seeds (aka "plus" trees) (Mahalovich and Dickerson 2004). Protection of trees from damage from wildland fire (prescribed, wildland fire use, or wildfire) is difficult and costly, yet it can be successful (Keane and Parsons 2010a; Murray 2007c). Mechanical manipulation of fuel surrounding the trees by (1) raking or blowing (via leaf blower) litter and duff away from tree bases, (2) cutting competing fir and spruce, and (3) manual removal of downed woody, shrub, and herbaceous fuels has been attempted in other ecosystems with mixed success. Fire crews have wrapped large whitebark pine with fire shelters to protect against fire mortality with mixed results (Keane and Parsons 2010a). There are also anecdotal stories of marginal successes by foaming trees to lessen fire damage. Modification of ignition patterns by controlling burn severity using strip head fires ignited in thin strips may be the most successful way to minimize fire-caused pine mortality in prescribed burning or back-burning in wildfires.

All HEFNP trees greater than 4.0 inches DBH appear to be susceptible to mountain pine beetle mortality (Gibson and others 2008; Logan and Powell 2001; Logan and others 2003). Most HEFNP species often avoid contact with mountain pine beetle by living in cold, inhospitable mountaintop environments where mountain pine beetles can't complete their life cycle. However, the recent winter-time warming trend has facilitated successful mountain pine beetle outbreaks in HEFNP forests across North America (Bentz and others 2010, Bentz and others, this proceedings). Improving tree vigor by removing competing trees probably won't increase the pine's ability to ward off beetle outbreaks, and it may cause additional stress that makes trees more susceptible to mountain pine beetle attack (Baker and Six 2001). Managers can protect valuable rust-resistant trees from mountain pine beetle using either pesticides or pheromone treatments. Carbaryl is probably the most effective pesticide treatment, especially when beetles are below outbreak levels. Carbaryl has been shown to provide greater than 90 percent protection for 2 years (Gibson and Bennett 1985). The anti-aggregation pheromone Verbenone is currently being used to protect whitebark and limber pine trees during beetle epidemics (Bentz and others 2005; Burns and others 2010; Kegley and Gibson 2004). Even when mountain pine beetle populations are at epidemic levels, managers should also consider using Verbenone or spraying Carbaryl on high value trees within the stands where restoration treatments are implemented (Baker and Six 2001), even though there are some circumstance where Verbenone may have mixed effectiveness.

The proximity of the alternate host in WPBR life cycle, mostly Ribes species, to HEFNPs is a poor predictor of rust incidence (Newcomb 2003), therefore removal of Ribes does not offer an effective method of controlling blister rust in these mountain ecosystems. Pruning rust-infected branches from HEFNP pines might delay the spread of rust in the early stages of invasion, but this also delays the selection against susceptible pines and therefore delays the selection for rust resistance (Schoettle and Sniezko 2007). Sanitation pruning of infected limbs may be effective for extending survival of high value trees, but is not suitable for application on a forest scale. The use of fungicides to battle rust epidemics is costly and ineffective and not practical because of the sheer number of trees to be protected. The best approach is to promote natural regeneration and diverse age class structures to maintain ecosystem function and provide large populations for selection for rust resistance (Schoettle and Sniezko 2007).

Monitor Treatments

The success of future HEFNP restoration efforts will be greatly dependent on the lessons learned in current and past attempts (Keane and Parsons 2010a). Managers and scientists will both benefit by the detailed documentation of the effects, successes, and failures of restoration attempts—no matter the scale, intensity, and extent of treatment implementation. Allocating resources for monitoring restoration treatments using statistically credible sampling designs is critical for providing the essential information needed to fine tune this restoration strategy to local areas and adjust treatment recommendations to improve efficacy. The first need for monitoring efforts is a comprehensive system of protocols, databases, and sampling methods for implementing a monitoring project. There are several monitoring systems available including FIREMON (Lutes and others 2006), the FIREMON-FEAT Integration, the Forest Service's FSVEG, and the National Park Service's Fire Montoring Handbook (USDI 2001).

The next need is for the collection of all monitoring data for analysis at various time intervals. These data then need to be analyzed at the local, regional, and national scales to document ecosystem responses and timing of response to restoration treatments for modifying restoration designs. Next, results from these monitoring efforts need to be published so they are readily available. Last, these monitoring efforts need to be maintained well into the future because of the long response times in HEFNP ecosystems. There is a role for both management and research in restoration monitoring—management could collect the data while research could analyze and report the data, for example. However, the primary role of research should be to explore new aspects of HEFNP ecology, genetics and restoration so management can adapt their methods to respond to these rapidly changing times.

Proactive Strategy for Threatened Ecosystems

Not all HEFNP ecosystems have been invaded by white pine blister rust, though all are vulnerable to impacts. There is an opportunity with proactive management to enhance currently healthy HEFNP ecosystems to retain ecosystem function during the naturalization of the rust (fig. 7). The Proactive Strategy articulates the goals, identifies the critical information needs, and outlines how to develop a management plan for early intervention (Schoettle 2004b; Schoettle and Sniezko 2007; Schoettle and others, The Proactive Strategy for Sustaining Five-Needle Pine Populations, this proceedings).

The goal of proactive intervention in these ecosystems is to increase resiliency and sustainability of ecosystem functions in the presence of the spreading rust and other threats such that ecosystem impairment in the future is mitigated (Schoettle and Sniezko 2007). Healthy, functional ecosystems are better able to respond to management than heavily impacted ecosystems. Therefore, there are more management options available and the potential for a successful outcome is improved. We know that WPBR can kill trees of all ages and disease impacts the regeneration capacity of pine populations (Schoettle and Sniezko 2007). As a result, efforts to stimulate regeneration after the population is heavily impacted may be compromised due to seed and disperser limitations (McKinney and others 2010; Keane and Parson 2010b). Interventions in healthy ecosystems can avoid possible regeneration failure that constrain management options and affect outcomes. Our experience with WPBR impacts in whitebark pine ecosystems (Tomback and others 2001b and papers within), suggests that waiting for populations to be impacted before acting isn't advisable.

Promoting early selection and establishment of resistant genotypes provides time for the resistant seedlings to mature to seed-bearing age before high mortality in the mature susceptible trees, thereby reducing the window of time when the ecosystem's recovery capacity is compromised. Three approaches, two at the stand scale and one at the landscape scale, to proactively facilitate an increase in rust resistance and mitigate the impact of the mortality of rust-susceptible trees have been developed (Schoettle and Sniezko 2007). Stimulating natural regeneration can increase population size, multiplies genetic combinations, and promotes efficient selection for resistance in the younger cohorts when rust arrives. Additionally, planting rust-resistant seedlings before rust has impacted an area can directly introduce

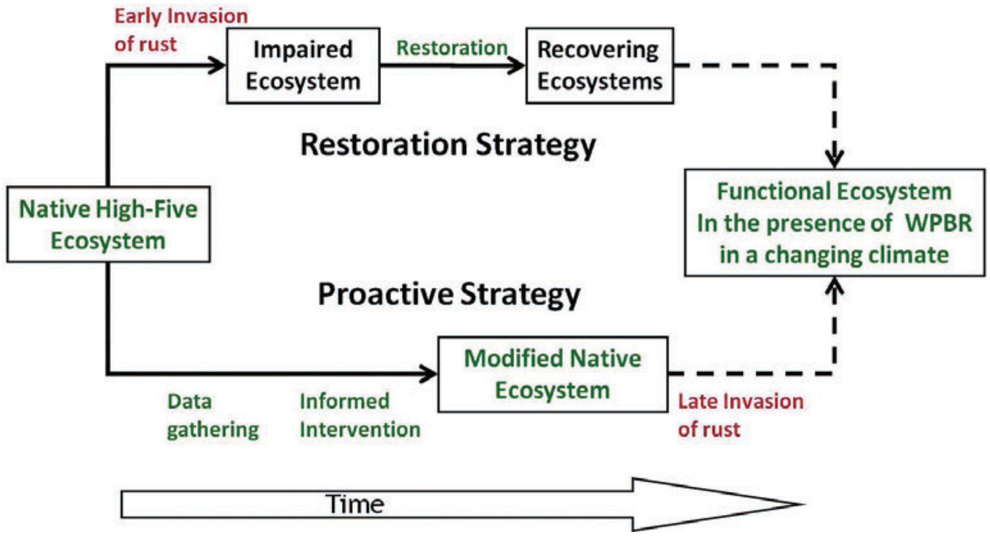

Figure 7. Schematic of the pathways to facilitating the transition of high elevation five-needle pine ecosystems threatened by white pine blister rust to functional ecosystems in the presence of white pine blister rust. If ecosystems have been invaded and are currently heavily impacted by white pine blister rust, the Restoration Strategy pathway would be followed (upper pathway) to restore ecosystem function. In ecosystems threatened but not yet heavily impacted by white pine blister rust, the Proactive Strategy would be followed (lower pathway) to sustain ecosystem function.

rust-resistant genotypes to the population. Diversifying the age class structure across the landscape will also result in rust-resistance selection (mortality of susceptible pines) proceeding at different rates in different patches that ultimately reduces the impact of mortality in any one cohort on ecosystem services. A mosaic of stand structures and ages positions the ecosystem for rapid and efficient natural selection for resistance in the younger cohort while the older cohort sustains ecosystem function (Schoettle 2004b). A structurally diverse landscape is also more resilient to mountain pine beetle impacts and has greater adaptive capacity to climate change. To conduct these interventions requires resources and process-level information on how these little-studied ecosystems respond to perturbation.

Efforts to prepare for the invasion of WPBR into the southern Rockies started in the late 1990's with the discovery by a graduate student of white pine blister rust on limber pine in Colorado (Johnson and Jacobi 2000). This event, while predictable, served as a wake-up call that the HEFNPs of the southern Rockies were at risk. Other isolated infection centers in central and southern Colorado, New Mexico, and Arizona have also been found (for example, Blodgett and Burns 2004, Kearns and Jacobi 2007) and demonstrate that blister rust continues to spread. WPBR was confirmed for the first time on RM bristlecone pine in 2003 in south-central Colorado (Blodgett and Sullivan 2004); this location is over 200 km from the nearest known inoculum source emphasizing the urgency for action because it is difficult to predict the epidemiology of the disease in these new habitats. Most southern Rocky Mountain HEFNP ecosystems are not yet impacted and this area is still considered the leading edge of WPBR spread.

The proactive approach was introduced in 2004 (Schoettle 2004), developed in 2007 (Schoettle and Sniezko 2007), integrated into a management framework for the HEFNPs in the central Rocky Mountain region in 2008 (Burns and others 2008), and currently implemented in the southern Rocky Mountains (Schoettle and others this proceedings, The Proactive Strategy for Sustaining Five-Needle Pine Populations). The combination of the mountain pine beetle outbreaks with the spreading WPBR is particularly threatening to the high elevation ecosystems in the southern Rocky Mountains because of their disjunct patchy distribution.

Unique opportunities and challenges face researchers and land managers interested in proactively increasing the resiliency of HEFNP ecosystems. These include: (1) educate and engage the public and managers to manage for resiliency, (2) conserve genetic diversity from native populations before they are impacted by WPBR and other stresses, (3) research patterns, processes and responses of native ecosystems to provide process level understanding of ecosystem behavior and (4) develop and implement management actions that increase the resiliency of HEFNP ecosystems to prepare them for change. Each are discussed below with examples from the southern Rockies.

Educate and Engage

Preparing to perform interventions in the traditionally unmanaged HEFNP ecosystems requires acceptance and engagement of land managers and the public. The long lifespan of the trees conveys a sense of perseverance that encourages the misconception that the species are invincible. While processes are slow at the higher elevations, so will be restoration and ecosystem response to intervention. The absence of dead trees on the landscape requires additional evidence of the validity of the threat for it to be competitive for management resources. Because this strategy requires engagement of land managers, public, research, and agencies, education is essential to reveal the vulnerabilities of these ecosystems.

Increasing awareness of the threats to the HEFNP ecosystems will facilitate a shift from crisis management to managing for sustained resilience. Most managers thought the southern Rocky Mountains and the Great Basin HEFNP ecosystems were too dry to support the disease. Quantitative estimates of the risk of rust impacts to HEFNP ecosystems are a critical first step to raise awareness of the threat to these ecosystems. Utilizing meteorological conditions to predict rust incidence, a risk analysis reveals that approximately 50 percent of the white pine ecosystems in Colorado have conditions on average that will support the disease (Howell and others 2006; Kearns 2005). Those sites without the appropriate conditions annually may also be vulnerable to infection intermittently.

Mapping spatial distribution and locations of the HEFNPs, WPBR, and other damage agents (mountain pine beetle, dwarf mistletoe) is also essential for elevating awareness of the threat to regional forest health and ecosystems services. In the southern Rocky Mountain HEFNP forests, field assessments began in the late 1990's (Harris and others 1999) and installation of additional monitoring plots continue. Plots from both extensive monitoring and intensive epidemiological studies are installed in both limber pine and RM bristlecone pine stands (Burns 2006; Kearns and Jacobi 2007). Permanent plots to assess the spread of rust from the new disjunction infection center in southern Colorado were installed in 2004 (Burns 2006).

Providing a forum for information exchange and dialogue among the diverse interest groups is critical. Establishment of the Central Rockies White Pine Health Working Group has served this purpose in the Southern Rockies. This group's annual meetings are open to all and often include presentations, discussions, and training sessions for forest health professionals, government and university researchers, land manager and resource professionals from multiple county, state and federal agencies, agency administrators, regulators, students, and other interested people. The meetings and follow-up interactions greatly increase awareness of the vulnerability of HEFNP resources in the central and southern Rockies and promote engagement and partnerships.

Management of federal lands includes extensive public involvement and therefore also requires public education. Recent research has revealed that people value HEFNPs for recreation and tourism; however, the primary reason for public support for managing forests under threat of WPBR is the continued existence of the forest for future generations (Meldrum and others, this proceedings). This indicates that with education and engagement, public support for proactive management is likely.

An educational website that serves as a primer on high elevation white pines, their ecosystems and the factors that threaten them provides easily accessible information for managers, teachers and the public (Schoettle and Laskowski 2006). Extensive seminars and training sessions to environmental, native plant and botanic garden interest groups also increase awareness. Coordination with local chapters of the Society of American Foresters has led to field tours in Colorado and Wyoming and their volunteer assistance with cone collections on the Medicine Bow NF. News media also helps increase awareness through targeted outlets such as newspapers, newsletters and public radio.

Gene Conservation

Blister rust can reduce genetic diversity (Kim and others 2003) and population size of the HEFNP hosts. Before rust affects the population, there is opportunity to capture the native species' genetic diversity for gene conservation, research and future management activities. Seed collections began in 2001 for RM bristlecone pine and in 2003 for limber pine in the Southern Rocky Mountains (Schoettle 2004b). Extensive collections are being made before the occurrence of high mortality caused by mountain pine beetle or blister rust, enabling research on adaptive traits, genetic structure and rust resistance screening to proceed (see below). Range-wide Rocky Mountain bristlecone pine collections, accompanied by stand condition plot information for each sampling location, will be complete soon. Contrary to past accounts of extremely infrequent seed crops in RM bristlecone pine, first year conelets occur most years on at least on some trees in every stand and some seeds mature each year. Bumper crops appear to occur every two to four years although synchrony of cone production is not tight among mountain ranges or sites within a range (Schoettle, unpublished data). Limber pine cone crops are less reliable with bumper crops every four to five years with smaller crops in intervening years and minimal to no production in some years in some populations. Seed and cone insects reduce seed yields in both species but are especially detrimental in limber pine following mast years at lower elevations (Schoettle and Negron 2001). The effect of warming in the treeline habitats on the distribution of seed and cone insects warrants research attention.

Research Patterns, Processes and Responses

Ecological and genetic information is scarce for HEFNPs compared to commercial tree species, and even the most basic information may be unavailable (Schoettle 2004a). Getting started early to fill the scientific knowledge gaps facilitates development of effective management resources and treatments. This information can best be gathered in healthy ecosystems to provide essential baseline information from which evaluation of disturbance (disease, insect outbreaks, climate change) and management outcomes can be compared. In addition, process-level understanding of natural disturbances and management responses enable models to be parameterized specifically for HEFNPs (Schoettle and others, this proceedings, A Population Genetic Model for High-Elevation Five-Needle Pines).

Studies of the disturbance ecology and colonization dynamics of southern Rocky Mountain HEFNPs can help develop silvicultural prescriptions that utilize natural processes to stimulate regeneration and diversify the age class structure of the pines. Stand-replacing fires were thought to be the primary disturbance regime (Baker 1992), although more recent studies suggest a mixed fire regime is also common (Brown and Schoettle 2008). Analyses of the spatial colonization of recent burns reveals that small patch burns are effective for regenerating RM bristlecone pine and limber pine in southern Colorado, while larger burned areas support greater limber pine regeneration in northern portion of the state (Coop and Schoettle 2009). This study also revealed that the temporal dynamic of regeneration for the HEFNPs in the southern Rockies is very protracted after disturbance. These patterns are being used to develop prescriptions to stimulate regeneration and evaluate future treatment effectiveness.

The concern that the use of fire as a silvicultural tool in high elevation pine ecosystems could increase the spread of invasive weed species is currently not founded in the southern Rocky Mountains (Coop and others 2010). *Ribes* cover was greater following fire (Coop and others 2010, Schoettle and others 2003), although the dominant *Ribes* species is a poor host for WPBR. The effect of this increase in *Ribes* cover on rust hazard is unknown and deserves further study. The benefits of increased regeneration with these treatments to the sustainability of the population will likely outweigh the marginal increase in rust hazard.

Microtopographic structure (nurse objects such as boulders, cobble, logs, and tree trunks) are important for successful establishment of both wind and bird-dispersed HEFNPs species (Coop and Schoettle 2009). Management focused toward promoting regeneration should ensure a high density of such objects. These patterns and microsites observed for natural regeneration help guide artificial planting guidelines (Casper and others this proceeding) and other silvicultural prescriptions.

Healthy ecosystems provide opportunities to gain information on the genetic structure of the pine host and population vulnerabilities to WPBR and other novel stresses, such as climate change. Seed zones were established for limber pine in 2006 (Maholovich 2006) and are in the process of being defined for RM bristlecone pine. The first adaptive traits study for RM bristlecone was initiated in 2002, and results will be used to aid in defining seed transfer guidelines. To further refine seed zones and guide gene conservation collections the genetic structure of RM bristlecone pine in the core portion of its range was studied using isozyme analyses in collaboration with the U.S. Forest Service's National Forest Gel Electrophoresis Lab (Schoettle and others, these proceedings Geographic patterns of genetic variation and population structure in *Pinus aristata*, Rocky Mountain bristlecone pine). Rust resistance testing of RM bristlecone began in 2004 and 2005 at Institute of Forest Genetics and Dorena Genetic Resource Center, respectively (Vogler and other 2006, Schoettle and others, Preliminary Overview of the First Extensive Rust Resistance Screening Tests of *Pinus flexilis* and *Pinus aristata*, this proceedings). The first extensive family-based rust resistance testing for limber pine began in 2006 (Schoettle and others 2010). Resistance is confirmed and the frequencies of those resistances vary geographically in both species.

Preparing the Landscape for Change

The proactive strategy focuses management on maintaining genetic diversity, facilitating the functional regeneration cycle, and promoting sustained adaptive capacity and ecosystems resiliency to novel stresses such as WPBR and climate change. We are just at the beginning of the implementation of treatments to work toward these goals. Specific proactive management plans have been prepared for Bureau of Land Management land in Wyoming (Means 2010) and are in preparation for Rocky Mountain National Park and Forest Service lands in northern Colorado; others are being considered.

Geographic variation in rust resistance and regeneration for HEFNPs as well as the coincidence of these factors with other stressors provide critical information to prioritize areas for seed collections and artificial regeneration or silvicultural treatments to stimulate natural regeneration (Schoettle and others, this proceedings, The Proactive Strategy for Sustaining Five-Needle Pine Populations). Populations with low frequencies of resistance are candidates for artificial regeneration with rust-resistant stock while those populations with higher frequencies are prioritized for seed collections and treatments that stimulate natural regeneration. Populations imminently threatened by disturbance are also a high priority for seed collections and protection.

The southern Rockies are poised to have the seed and technology to support artificial regeneration projects for limber pine and RM bristlecone pine. Extensive seed collections have been made and seed sources shown to have rust resistance are being protected from mountain pine beetle for both limber pine and RM bristlecone pine. Limber pine and RM bristlecone pine have been added to several National Forest seed procurement plans, and operational collections have begun on National Forest, National Park Service, Bureau of Land Management and county lands.

Any early establishment of rust-resistant seedlings will benefit the ecosystems over the long run. The high elevation five-needle pines are slow growing and require 30-50 years to produce their first seeds and much longer to reach full reproductive maturity (Schoettle 2004a). Proactive establishment of resistant seedlings would close the gap in time, upon invasion, between rust-impaired seed production of the susceptible older cohort and seed production of the resistant younger cohort (Schoettle and Sniezko 2007). Guidelines for planting limber pine in the southern Rockies are being developed (Casper and others, these proceedings).

Utilizing the information gained by ongoing and previous research, silvicultural prescriptions to stimulate high elevation five-needle pine regeneration have been prepared and are being implemented on the Pike and San Isabel National Forests in Central Colorado (Floyd Freeman, Salida RD, San Isabel NF, unpublished reports). Treatments use mechanical thinning and group selection; conditions have not yet been conducive for the use of prescribed fire. Pre- and post-treatment monitoring plots have been installed to assess new regeneration, release of advanced five-needle pine regeneration and mountain pine beetle impacts. Because of the protracted regeneration dynamics for HEFNP species (Coop and Schoettle 2009), the effectiveness of the treatments can't be fully evaluated for at least 10 years. As more treatments are installed, the more structurally diverse landscape should mitigate the impacts of mortality in any one cohort on ecosystem services and provide greater adaptive capacity to climate change. Silvicultural prescriptions to manage limber pine at the lower elevations have also been prepared for Bureau of Land Management lands in Wyoming (Means 2010).

The implementation of the Proactive Strategy in the southern Rockies has yielded vital information to sustain these valued ecosystems before white pine blister rust and mountain pine beetle caused extensive mortality of HEFNPs. Extensive outreach and education has engaged committed and diverse groups of managers, forest health professionals, researchers and local citizen groups. Management options for sustaining HEFNP in the southern Rockies and the Southwest have been prepared and intensive management plans are in preparation for northern Colorado. We have gained resources and knowledge that would not have been possible if had we waited until white pine blister rust had affected the populations and ecosystem functions. Active partners have been engaged to conserve the resource and gain critical information needed to take action before the ecosystems are heavily impacted. With early and committed management, we are optimistic that the HEFNP ecosystems will be sustainable in the presence of the rust and have improved resiliency to adapt to the changing climate.

Discussion

We have outline two strategies for the management of HEFNP ecosystems: the Restoration Strategy for restore ecosystem function in declining systems and the Proactive Strategy to sustain ecosystem function in threatened systems. The goal of both strategies is to promote self-sustaining five-needle pine ecosystems that have resilience to disturbances and genetic resistance to white pine blister rust. The strategies take different approaches based on the initial condition of the ecosystem. On landscapes currently impacted and degraded by WPBR and other stresses, the Restoration Strategy restores ecosystem function by reconstructing pine populations and reinstates disturbance regimes. Alternatively, in HEFNP ecosystems threatened by WPBR but not yet affected, the Proactive Strategy increases ecosystem resiliency to maintain ecosystem function throughout the naturalization of the rust. Many of the genetic and silvicultural tools are similar yet their applications differ among the two approaches. We have outlined the approaches for both strategies and presented examples of their implementation in declining and threatened HEFNP ecosystems. Sharing knowledge gained by the execution of either approach will provide valuable information to improve management of HEFNP ecosystems throughout western North America.

There is concern among some scientists and managers that treating declining or healthy HEFNP ecosystems during a time when mountain pine beetle outbreaks are rampant, extensive blister rust infection looms large, and the climate is rapidly changing might be fruitless and counterproductive by adversely impacting pine seed sources and by being an inefficient use of restoration funding. However, we feel these factors only further highlight the pressing need for immediate action and they provide a rational for strategic research and management planning for these slow-growing species. Sustaining ecosystem function on these valued landscapes requires understanding the ecosystems. The devastating impacts of the combination of white pine blister rust and mountain pine beetle and the unknown outcomes of climate change suggest that time for understanding these ecosystems cannot be delayed.

Allowing wildland fires to burn or lighting prescribed fire could kill cone bearing HEFNP trees and some feel that this may be counterproductive to restoration efforts. These concerns seem valid, but perhaps we should consider the alternative. Wildfires will happen regardless of our best suppression efforts, especially in these high elevation ecosystems that sit on the tops of mountains where most fires originating from dry forests below will eventually spread, and these unplanned wildfires might have a greater chance of killing valuable rust-resistant individuals than managed fires because uncontrolled wildfires tend to burn under drier, hotter, and windier conditions (Black 2004). Moreover, the seeds from these surviving, stressed trees would have a lesser chance of being sown in favorable sites free of competition because there could be fewer burned areas on the landscape due to reduced fires. Mountain pine beetle impacts on pine are devastating, but these impacts are no reason to suspend restoration activities, but rather they serve as a reason to accelerate seed collections for rust resistance testing, restoration plantings, and gene conservation. In fact, this might be the most important time to initiate management actions on the landscape to ensure HEFNP species will continue to inhabit high elevation forests into the future.

Restoring high elevation pine ecosystems is further complicated by other political and administrative barriers (Salwasser and Huff 2001). Since most HEFNPs are on public lands and they have little commercial potential for timber, agency funding and support is not as strong as for other timber species. Social acceptance of management in these high elevation ecosystems may be less of an obstacle. Initial surveys document that people value HEFNP forests and may support management to sustain their existence for future generations (Meldrum and others, this proceedings). Integration of public preferences with economic and ecological trade-offs will provide further insights into potential optimal management strategies (Bond and others, this proceeding). The U.S. Forest Service policy of not planting rust-resistant pine seedlings in Wilderness Areas is somewhat concerning since many high elevation ecosystems in the western U.S. are within designated Wilderness Areas (Keane 2000). The potential listing of whitebark pine as a threatened species under the Endangered Species Act may also pose both administrative challenges and opportunities. And the linkage of grizzly bear politics with whitebark pine may add an additional layer of complexity to the management of the HEFNP. All of these barriers can be overcome if comprehensive strategies can demonstrate the value of these ecosystems, provide a viable process for restoring and sustaining these forests, and show the dire consequences if these species are lost from the high elevation landscape through inaction. The crisis for whitebark pine has brought increased awareness to the severity of the combined threats of white pine blister rust, mountain pine beetle, and climate change to the other HEFNPs that have not yet been impacted as severely. A shift is beginning toward managing these still healthy ecosystems for resilience to these novel stresses to position them on a different trajectory from that followed by whitebark pine. HEFNP restoration management will take centuries and we must commit to a strategy for the "long haul". While it may seem that restoring high elevation pine forests is a monumental task with questionable outcomes, we believe that sustaining and restoring these forests is not only achievable, but essential for the long term sustainability of high mountain landscapes.

The key to successful restoration is facilitating the increase in rust resistance on the landscape, whether it is through natural selection or planting of rust-resistant pine seedlings after disturbance. Wildland fires, whether these fires are wildfires, controlled wildfires, or prescribed fires, are important disturbances for whitebark pine restoration and may also serve as an important component of management plans for the other HEFNP species. It is also vital that the genetic diversity of planted seedlings be maximized while also including rust resistance traits, to ensure HEFNPs forests remain on the landscape as the changes in climate alter landscape processes. The free flow of genetic material across the landscape using natural wind and bird-assisted seeding, along with human-assisted planting, may be our best strategy for sustaining pines on the high elevation landscape.

Management to sustain HEFNP populations in the presence of white pine blister rust, mountain pine beetle, and climate change has never been more important. The threats and their impacts are clear and are playing out on the landscape right now. Whitebark pine and some populations of limber pine are the harbingers of what is to come for the other HEFNP populations if no action is taken. Restoration of these hard hit areas are needed and it is time to act to prepare to sustain the other species as they are increasingly challenged by these inescapable threats. Early information gathering, planning and intervention will mitigate development of impacts in currently healthy populations and immediate action is required to restore function to those stands already impacted. Whether it is restoring impacts landscapes or interventions to mitigate the development of impacts on threatened landscapes, there are two important factors that will govern the success of HEFNP species even with comprehensive and effective rangewide strategies: (1) the amount of resources available over time to conduct restoration efforts, and 2) the commitment of natural resource agencies to conduct restoration activities over the long term, most likely for many decades to centuries.

Acknowledgements

We thank of the USDA Forest Service Rocky Mountain Research Station for their extensive fieldwork on this study. We also thank Rocky Mountain Research Station for technical reviews. We thank Diana Tomback, University of Colorado at Denver; Russ Parsons, U.S. Forest Service, Rocky Mountain Research Station; and two anonymous people for technical reviews.

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