Guidelines and Best Practices for Managing Fire in Whitebark Pine Stands in the Crown of the Continent

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Abstract: This document details a fire management strategy for facilitating the restoration of whitebark pine on subalpine landscapes of the Crown of the Continent (COTC). The heart of the management strategy is Table 1 that specifies the most appropriate fire management action, including prescribed fires, before, during and after a wildfire. This report first justifies the need for special attention in fire management practices when in the upper subalpine landscapes of the COTC. Next, we detail a set of management actions that will enhance whitebark pine restoration before and during a wildfire. All restoration actions, including mechanical thinnings, prescribed burning, and wildland fire use, are also fuel treatment activities that allow effective suppression of wildfires when needed. Therefore, several types of prescribed burn and mechanical thinning restoration actions are defined and detailed to provide context for Table 1. And last, the three wildfire management strategies -- full suppression, partial suppression, and wildland fire use (letting some fires burn under prescribed conditions), are defined and discussed, and the strategies for their use are documented in the context of whitebark pine restoration in Table 1.

Introduction

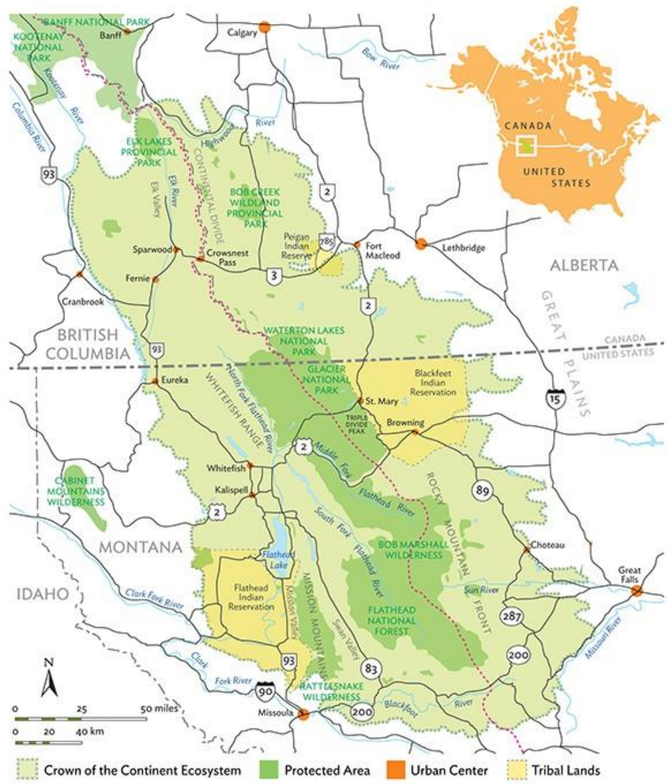


Figure 1-The Crown of the Continent ecosystem (COTC)

Whitebark pine (*Pinus albicaulis*) is a five-needle pine and is considered a keystone species in subalpine ecosystems throughout much of western North America, especially in the iconic high mountain landscapes of the Crown of the Continent (COTC) (Figure 1) (Tomback and Achuff 2010). In Canada, whitebark pine populations are concentrated throughout southern BC mountain ranges and on steep southwesterly aspects above 1500m in Alberta's Rocky Mountains (Wilson 2007). This relatively rare tree species provides well-rooted resistance to soil erosion in harsh mountain environments, and provides a critical food source for a range of small and large mammals, including grizzly bears, with its nutrient rich seeds contained within its purplish cones (Farnes 1990). The whitebark pine shares a rare mutualistic relationship with the Clark's nutcracker (*Nucifraga columbiana*), because the cones are indehiscent (do not open without force applied), the tree species must rely on the nutcracker to open them. Whitebark seed is a primary and critical food source for the nutcracker and the nutcracker preys upon the whitebark pine's ripe cones and caches the seeds across the subalpine landscape for later retrieval (Tomback 1998). The tree benefits by having its seeds dispersed - allowing for otherwise impossible germination - as not all of the cached seeds are retrieved and may germinate and become whitebark pine forests of tomorrow (Lanner 1985).

Whitebark pine is rapidly declining throughout the COTC due to the combined effects of historical and current mountain pine beetle (MPB) outbreaks, fire exclusion, climate change and the introduced pathogen *Cronartium ribicola*, which causes the disease white pine blister rust (WPBR) (Keane and Arno 1993, Kendall and Keane 2001a, Kendall and Keane 2001b)(Keane and Arno 1993, Smith et al. 2012, Keane et al. 2012). The loss of this tree species has implications for the integrity of COTC subalpine ecosystems, both in the loss of biodiversity and the loss of ecosystem processes and services that provide habitat requirements for other species such as Clark's nutcracker (Tomback and Achuff 2010). WPBR and MPB contribute directly to mortality while the combination of fire exclusion, WPBR and MPB serves to accelerate succession and provide competitive advantages to shade-tolerant tree species, including subalpine fire and Engelmann spruce, which will ultimately outcompete the five-needle pine within its lower elevation range (Keane 2012). Climate change, among other influences, can reduce habitat advantages of high elevation pines with respect to competition species, and cause marked shifts in disturbance regimes that are critical to long-term survivability (Keane et al. 2016; Dale and others 2001). Fire is a critical disturbance in developing whitebark pine forests as it consumes dense mats of organic material to expose a more prolific mineral soil seed bed and reduces competition by killing less fire resistant, shade-tolerant species (Larson et al. 2009).

There have been numerous management guides written to facilitate the restoration of declining whitebark pine ecosystems. Keane et al. (2012) wrote a rangewide strategy for restoring whitebark pine and then Keane et al. (2016) wrote a companion guide to the rangewide strategy that discusses how to conduct restoration activities in the context of climate change. There have been several other restoration strategies written by land management agencies for implementation at smaller regions such as the Greater Yellowstone Ecosystem (Greater Yellowstone Coordinating Committee Whitebark Pine Subcommittee 2011), the Pacific Northwest (Aubry et al. 2008b), and Glacier NP (Peterson 1999). Recently, there has been interest in establishing a restoration strategy for five-needle pines (5NP) in the COTC (Nelson 2016). However, before that can be written, there needs to be an explicit strategy and corresponding best management practices of how we will manage wildland fire (wildfires, wildland fire use, and prescribed fires) on COTC landscapes in the context of whitebark pine restoration. How wildfires are managed in an area can dictate the success or failure of whitebark pine restoration treatments, and vice versa, there are many whitebark pine restoration actions that can enhance the success of wildland fire management in whitebark pine forests. This report details general management actions and best practices for managing fire in the COTC.

Background

Whitebark pine historical fire regimes

Whitebark pine fire regimes often contain elements of all three types of fire severities: non-lethal, mixed severity, and stand-replacing (Morgan and Bunting 1989, Arno and Hoff 1990, Murray et al. 1998, Barrett 2008, Larson et al. 2010) (Figure 2). Some whitebark pine stands may experience low-intensity, non-lethal surface fires because of sparse surface and canopy fuel loadings and unique topographical settings. These sites are mostly found in the southern parts of the species range in the Rocky Mountains or on high, dry ridges, and represent only a small portion of existing whitebark pine forests (less than 10 percent) (Keane and Morgan 1994, Morgan et al. 1994). Whitebark pine may survive low-intensity surface fires better than most of its competitors, especially subalpine fir, because it has somewhat thicker bark, higher and thinner crowns, and deeper roots (Ryan and Reinhardt 1988). Non-

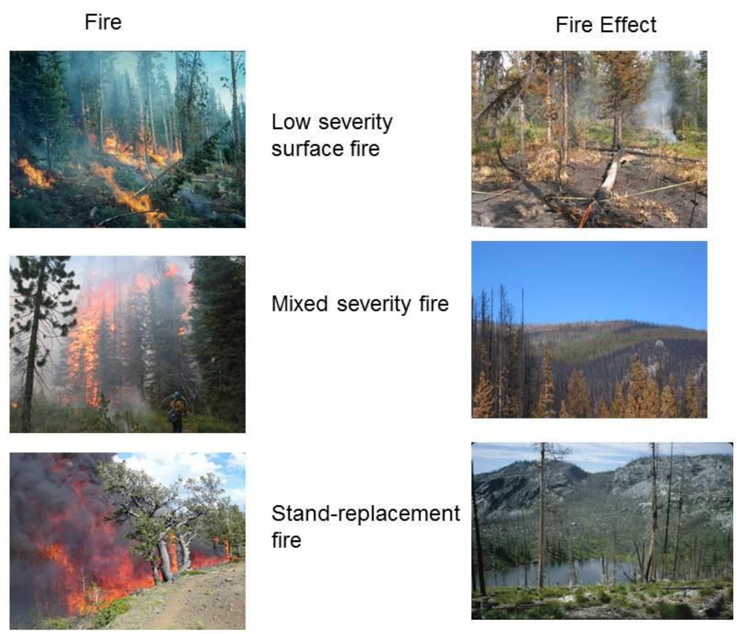


Figure 2-The three types of fire regimes observed in whitebark pine forests

lethal surface fires have historically maintained whitebark pine dominance in the overstory and prolonged whitebark pine cone production by delaying succession (Keane 2001).

The more common, mixed-severity fire regime is characterized by severities that are highly variable in space and time, creating complex patterns of tree survival and mortality on the landscape (Romme and Knight. 1981, Murray et al. 1998) (Figure 2). Mixed-severity fires can occur at 60 to 300+ year intervals and sometimes over 500 years, depending on drought cycles, fuel conditions, landscape burn history, and frequencies of high wind events (Morgan and Bunting 1989, Morgan et al. 1994, Larson et al. 2010). Individual mixed-severity fires can be patches of non-lethal surface fires with differential mortality mixed with patches of variable mortality stand-replacement fires. Sometimes fires burn in sparse ground fuels at low-severities, killing the smallest trees and the most fire-susceptible overstory species, often subalpine fir (Walsh 2005). Severities increase if the fire enters areas with high fuel loads or if there are high winds or drought conditions because these situations facilitate fire's ignition in tree crowns, thereby creating patches of fire-killed trees (Lasko 1990). Burned patches range widely in size depending on topography and fuels, and these openings provide important caching habitat for the Clark's nutcracker (Tomback et al. 1990, Norment 1991).

Many whitebark pine forests in the COTC historically experienced periodic large, stand-replacement fires that occurred at long time intervals (greater than 250 years) (Figure 2). Stand-replacement fires also occurred within mixed-severity fire regimes but as infrequent events (Romme 1980, Morgan and Bunting 1990). These fires are usually wind-driven and often originate in lower, forested stands (Murray et al. 1998), and they create large burned patches that may be distant from tree seed sources (Beighley and Bishop 1990). Whitebark pine has an advantage over its competitors in that it readily colonizes large, stand-replacement burns because its seeds are transported great distances by Clark's nutcracker (Tomback 1982, 2005, Lorenz et al. 2008). Nutcrackers can disperse whitebark pine seeds up to 100 times farther (over 10 km and sometimes up to 30 km) than wind can disperse seeds of subalpine fir and spruce (McCaughey et al. 1985). Since nutcrackers often cache in open sites with many visual cues, stands burned by mixed- or stand-replacement fire provide favorable sites for nutcracker caching and competition free seedling growth (McCaughey and Weaver 1990, Sund et al. 1991). Murray et al. (1995) found that larger burns were associated with greater volume per hectare of whitebark pine as compared to smaller burns in the Bitterroot Mountains.

Whitebark pine benefits from wildland fire because it is better adapted to surviving fire and also to regenerate in burned areas than associated shade tolerant trees (Arno and Hoff 1990). Without fire, most seral whitebark pine forests would be successionally replaced by subalpine fir or some other shade-tolerant high-elevation species. Fire, whitebark pine, and the Clark's nutcracker form an important high-mountain ecological triangle (Tomback 1989). Fire burns large areas and kill trees that then enhances fine-scale pattern that then facilitates nutcracker caching and the absence of competition post-burn allows forgotten seed caches to grow into mature trees in the absence of competition. Remove any one of the sides of the triangle and this keystone ecosystem is lost.

Objectives for fire management in whitebark pine ecosystems

Considering that fire plays an important role in whitebark pine ecology, there are several key objectives identified for the restoration of whitebark pine that concern fire management (Keane et al. 2012):

- Reduce mortality of known high value whitebark pine trees (e.g., plus trees - trees identified by managers to be putatively rust-resistant) and, when possible, reduce mortality of suspected high value whitebark pine trees (i.e., potential rust resistant trees)

- Reduce competitive, shade-tolerant tree species in high elevation whitebark pine communities through strategic consideration of prescribed fire planning and initiatives, mechanical cuttings, and wildfire management options.

- Increase post-fire whitebark regeneration through the creation of habitat that facilitates caching by the Clark's nutcracker and is also free from shade-tolerant competition so that the potential planting of resistant whitebark pine seedlings will be successful.

Definitions for terms used in this paper

When we define management actions and objectives, we will use terms that need a specific definition to be interpreted in the right context. Here are a list of terms that need to be specifically defined in this document:

High Value

> *Regeneration*. High value regeneration are whitebark pine seedlings that have been planted by management or identified as potentially being resistant to WPBR.
>
> *Trees*. High value trees are those mature whitebark pine trees that are identified as "plus" trees in various genetics programs. However, in this document we will also include those whitebark pine trees that are phenotypically resistant to blister rust as high value trees, such as trees that are surviving in areas with high (>90%) WPBR mortality or trees with obvious WPBR damage but are still living after a decade or more.

Low Value

> *Regeneration*. Low value regeneration are whitebark pine seedlings that are visibly suppressed or present in areas where their chance of being resistant to WPBR are extremely low (<1%).
>
> *Trees*. Low value trees are those whitebark pine trees that have more than 50% of their crowns killed by WPBR.

Management Actions

Restoration Strategies and actions

The rangewide strategy and most other regional restoration strategies emphasize the need to create conditions that facilitate whitebark pine regeneration, conserve rust-resistant seed sources, and promote rust resistance (Aubry et al. 2008a, Keane et al. 2012). These strategies include creating nutcracker caching habitat, reducing competing vegetation, decreasing surface and canopy fuels, manipulating forest structure and composition, and diversifying age class structure. These strategies are especially important to ensure whitebark pine remains on future landscapes under climate change. These strategies can be implemented on the ground using actions that include a host of passive and active treatments to create areas where whitebark pine can prosper. One of the most important objectives in nearly all whitebark pine restoration guides is to take a landscape approach and manage for heterogeneous landscapes to ensure resilience in the face of climate change (Turner 1987, Turner et al. 1989, Turner et al. 1992). It is important to note that all of these strategies, and the actions used to implement these strategies, are important to fire management in the whitebark pine zone, and vice versa. Restoration treatments act as de facto fuel treatments that can modify fire growth, provide safe zones to protect firefighters, and provide attack points for fire suppression activities.

Many types of treatments can accomplish the primary restoration objectives of facilitating whitebark pine regeneration, increasing whitebark pine cone crops through increases in vigor, and reducing disturbance impacts. This usually involves some combination of silvicultural cuttings, prescribed burning, and planting rust-resistant seedlings. These treatments should attempt to improve landscape heterogeneity while also facilitating whitebark pine resilience, rust-resistance, and sustainable cone crops.

Treatments are done for a variety of reasons. The elimination of competition from whitebark pine trees is meant to improve tree vigor, which is increasingly important as climate warms (Joyce 1995, Joyce and Birdsey 2000). Improved vigor often results in greater forest resilience because the vigorous trees are now about to allocate more resources to defenses against disturbances, which may increase under climate change. Improved vigor may also increase cone crop production in frequency and quantity because trees may allocate resources to reproduction (Aston 2010). And last, increased vigor will contribute to longevity and allow trees to remain on the landscape for long times (Bartos and Amman 1989).

Since climate change may result in significant increases in subalpine productivity (Joyce 1995, Wu et al. 2011), it is important to remove as many shade-tolerant competitors as possible to retard succession and make restoration treatments last longer (Keane et al. 2016). Therefore, there are several alternative designs to these competition-removal treatments to account for potential climate change. First, mechanical cuttings and prescribed burning treatments should take a more liberal approach and remove more of the competitors than normal to ensure reductions in competition. Cutting trees smaller than merchantable or removing advanced regeneration is probably best in the future, which may be costly and time-consuming if removing seedlings and saplings. In prescribed burning, it will be better to burn on the hotter side of the prescription while protecting those valuable plus trees. Therefore, we suggest that there be a pre-fire mechanical treatment, either fuel augmentation or reduction (Keane and Parsons 2010b) to add more fuels (needles and small branches) to the normally sparse fuelbed so that a greater intensity can be obtained while the weather conditions are still moist (Keane and Parsons 2010b). Some prescribed burns may be difficult in some operational settings because the fuelbed may be quite dry, which might increase the risk of escape, spotting, and high whitebark pine mortality. It is vitally important that any mechanical thinning or cutting to improve whitebark pine growing conditions should also treat the fuels surrounding the apparent rust-resistant trees to reduce the chance that they are lost from fire. And to make any mechanical treatment last long and become more effective, it is vital that prescribed burning be combined with mechanical cuttings where possible.

Prescribed burning, mechanical cuttings, and plantings are always mentioned as the primary tools for implementing treatments in the context of the treatment objectives, which can be competition removal, fuel reduction, fuel augmentation, and regeneration facilitation. However, the most effective treatments should be designed to address multiple objectives. But more important than any stand-level treatment are the fire management strategies that are used to decide the fire suppression activities in high elevation systems where these stands occur (Keane and Parsons 2010a). The general strategy of wildfire management in an area can dictate the success or failure of whitebark pine restoration treatments, and vice versa, there are many whitebark pine restoration actions that can enhance the success of wildland fire management in whitebark pine forests.

Fire Management Actions

There are basically three options for fire management on whitebark pine areas: full suppression (FS), partial suppression (PS), and allowing wildfires to burn under an acceptable set of conditions (WFU for wildland fire use). **Full suppression (FS)** entails attempting to suppress most fires in an area with a target success rate of 98%. Wildfire suppression involves attempting to contain any wildfire using various firefighting tactics such as fireline construction, retardant and water drops, and ignition operations. The suppression tactics that are usually employed can be stratified into two types: initial attack and wildfire management. In initial attack, crews are sent to extinguish fires when they are small (<40 ha) using wildfire suppression tactics to prevent them from becoming large. Initial attack tactics are quite effective and most land management agencies report initial attack using suppresses around 98% of all fires, even though it is estimated that around 70% of these fires would have probably stayed small anyway. Wildfire management, however, is when fires become large (>40 ha) and large-scale suppression activities must be used to contain the wildfire. Usually, wildfire suppression activities become less effective when fires get large; it is usually weather that suppresses large fires. **Partial suppression (PS)** is a term used only in this report, and it entails a strategy where suppression tactics are used on small areas to protect values at risk, sometimes called spot suppression. In this report, it might involve retardant or water drops to protect high value, rust-resistant whitebark pine trees.

The last fire management action, which is perhaps the most important restoration tool for landscape level, is controlled wildfires or **wildland fire use (WFU)**. WFU, which used to be called prescribed natural fires and "let burn" fires and now they are sometimes called "wanted wildfires", are lightning-started fires that are allowed to burn under acceptable weather and site conditions that are specified in a fire plan (Black 2004). We feel the aggressive use of WFU has the potential to be an efficient, economical, and ecologically viable method of restoring whitebark pine in many areas, especially wilderness. Landscapes where WFU might be contra-indicated are those with few whitebark pine seed sources both near and distant, but only if planting is an impossibility. Otherwise, most WFU will probably improve whitebark pine's status and health if the fires are carefully monitored to avoid mortality of potentially rust-resistant trees (i.e., linked with partial suppression actions). However, we recommend that burned areas in landscapes with high blister rust infection (greater than 50 percent) and mortality (greater than 20 percent) be planted after any wildfire with apparent rust-resistant whitebark pine seedlings (discussed at the stand and tree scale) to ensure future resilience.

Uncontrolled wildfires (i.e., **wildfires**), or wildland fires that are actively suppressed, may also be a *de facto* restoration tool at the landscape level. Large wildfires may be important for whitebark pine restoration in those areas of its 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 et al. 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 et al. 2008). Land managers and fire suppression management teams should view wildfires as a possible mechanism for restoring high-elevation systems and use ecologically based decision support tools, such as FLEAT

(Keane and Karau 2010) to decide whether or not to let wildfires create potential restoration sites for whitebark pine (Keane et al. 2016). Moreover, wildfire rehabilitation teams should evaluate the level of cone production and rust/beetle mortality in whitebark pine stands surrounding these large wildfires to assess if planting putative rust-resistant whitebark pine is necessary to ensure adequate regeneration. Wildfires, however, are NOT included in this report as a fire management action.

Fire management planning often results in the identification of areas where suppression may be required and areas where fires may be allowed to burn. But there are also treatments that management can install ahead of any wildfire that will reduce the potential impacts of a future uncontrolled wildfire event. These often involve fuel treatments along the wildland urban interface to reduce fire behavior so firefighters can directly attack the fire and prevent loss of life and property. However, there are also treatments that can be implemented prior to wildfires that will reduce the impact of severe wildfires on important and valuable ecosystems, such as the keystone whitebark pine forests. As mentioned above, there are numerous mechanical cuttings, prescribed fire, fuel, regeneration, and planting treatments that will enhance the restoration of whitebark pine while simultaneously reduce the potential unwanted damage of a future wildfire. These treatments can work in concert with wildfire to accomplish the goal of restoring whitebark pine ecosystems while reducing fuels and undesirable ecological effects from future wildfires. These treatments are discussed next.

Mechanical Cuttings

Mechanical cuttings are treatments that manipulate the stand by cutting trees. It is important to note that traditional silviculture has limited effectiveness in these high mountain stands because of the severity of the site, unique autecology of whitebark pine, and bird-mediated seed dispersal (Keane and Arno 2000). Novel silvicultural strategies that are tailored to individual stands are needed to address restoration concerns in whitebark pine (Waring and O'Hara 2005). In general, most cuttings should attempt to eliminate subalpine fir and other shade-tolerant competitors while enhancing whitebark pine vigor. Thinnings can be used to improve the health of potential cone-producing whitebark 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 (gentle slopes, few rocks, and few wet areas, for example).

Six types of mechanical cuttings are being used in restoration treatments for whitebark pine. Keane and Parsons (2010b) created **nutcracker openings** (**NO** in Tables 1, 2) in successionally advanced subalpine fir stands with healthy and dying, rust-infected whitebark pine. Nutcracker openings are a cutting treatment that attempts to mimic patchy, mixed severity fires. All trees except whitebark pine are cut in these openings. The size and shape of these areas may vary, but they can be anywhere from 1-30 acres based on a study by Norment (1991) who found that nutcrackers appeared to favor burn patches less than 15 ha in size. Another cutting treatment is **selection cuts** (**SEL** in Tables 1, 2) where all trees except whitebark pine are sawn down (group selections can be nutcracker openings). The primary purpose of both NO and SEL treatments are to enhance regeneration opportunities for whitebark pine by creating desirable caching habitat for the Clark's nutcracker. Mechanical **thinning** (**THIN** in Tables 1, 2), where chainsaws are used to cut competing shade tolerant subalpine fir, spruce, and mountain hemlock and shade intolerant lodgepole pine in some stands is the primary tool used for competition removal treatments. It is important that all competing shade-tolerant conifers be cut, including the regeneration, which is rarely done because of the cost. Any residual competing trees, even small seedlings, will compromise the efficiency of the mechanical treatment, especially when productivity increases projected for the future will accelerate successional advancement. Therefore, many cuttings can be improved by including prescribed burning after the cut because it will tend to kill most of the small and large shade-tolerant tree competitors and leave the more fire-tolerant whitebark pine individuals (Chew 1990, Eggers 1990, Burns et al. 2008). **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 tree biomass on the site which could provide fuel that fosters high severity wildfires that could kill the whitebark pine trees being restored. **Daylighting** (**DAY)** or the cutting of shade-tolerant competing species in a circular area around selected whitebark pine trees (area radius roughly equal to the height of the canopy) has been gaining favor among managers because it is cheap and easy, but there is little research on its effectiveness.

It is important to reduce or remove the slash from the treatment area to (1) allow nutcrackers 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 may be accomplished by (1) piling the slash and then burning the piles, (2) whole tree skidding to a landing which removes the boles and branches from the site, or (3) augmenting the cutting with a prescribed fire. Waring and Six (2005) found that *Ips* spp. beetles from slash piles move out and killed whitebark pine trees after one year. Cutting treatments can be offered as commercial timber harvests if (1) the trees are large enough, (2) the area is accessible by road, and (3) there is a market for the timber. Often, land management agencies have implemented cutting treatments using outside funding from various foundations or institutions because of the low timber value in treated stands.

Keane and Parsons (2010b) found that lodgepole pine trees could be left on site if they occur in low densities (less than 20 trees ha^{-1}) but this may change as climates warm. Whitebark pine can compete with lodgepole pine on most upper subalpine sites with acceptable whitebark pine regeneration and growth providing overstory lodgepole pine cover is low (less than 50 percent) (Arno and Hoff 1990; Keane and Parsons 2010b). Elimination of shade-tolerant competitors is the most important requirement of any cutting, and it is critical that the cone-bearing trees are eliminated first. Subalpine fir can have frequent cone crops with numerous seeds that will create dense fir stands. The most effective cutting treatments will be those that eliminate the most subalpine fir trees, starting with the cutting of cone-bearing trees first and then eliminating the carpet of fir regeneration. The presence of residual subalpine fir seedlings and saplings 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 longer. However, it is important to remove slash from serotinous cone-bearing lodgepole pine trees before burning to avoid overly dense lodgepole pine regeneration.

Prescribed burning

Prescribed burning alone, however, is not as exacting as mechanical cuttings because prescribed fire impacts are highly variable across space; parts of the stand may be lightly burned leaving many competing fir and spruce trees alive. It can also severely burn parts of the stand resulting in high mortality in mature whitebark pine trees (Keane and Parsons 2010a). If done correctly, prescribed fires can kill most of the shade-tolerant understory layer that would take significant effort if mechanical cuttings were used. This is especially true when fuels are augmented prior to the fire treatment. And prescribed burns can also reduce fuels for wildfire mitigation.

In this document, there are three kinds of prescribed fires. The prescribed fire at low intensity (**PFLI** in Tables 1, 2) is a planned fire at low intensities meant to mimic the non-lethal surface fire regime. The primary goal of this fire is to remove fir, spruce, and hemlock seedlings, saplings, and pole tree competition and increase the vigor of remaining mature cone-bearing whitebark pine trees. The prescribed fire at moderate intensity (**PFMI**) is implemented to emulate the mixed severity fire regime where small to large holes in the canopy are created by crowning and torching while the fire burns at lower intensities throughout the rest of the stand. This PFMI will hopefully create potential nutcracker caching habitat while also removing competition from other shade-tolerant trees. Last there is prescribed fire at high intensity (**PFHI**) that is meant to mimic a stand-replacement fire regime. In a PFHI, the fire essentially kills all trees and leaves a large, competition-free area for whitebark pine natural regeneration, and most importantly, an ideal area for planting rust-resistant whitebark pine seedlings. Most PFHIs are running crown fires or high intensity surface fires in stands with high fuel loadings. It is important that there are few seedlings and seed-source trees in the burned over area.

Fuel Treatments

Fuel treatments will undoubtedly play an important role in reducing wildfire impacts on living rust-resistant trees and are therefore considered a viable restoration action. Fuel treatments can take many forms, such as individual tree canopy and surface fuel removal, fuel augmentation for prescribed burning, and controlled and uncontrolled wildfires to create fuelbreaks. However, wildfires are difficult to plan and manage, especially once they get above 50 ha in size, and there is always a chance that they will adversely impact whitebark pine restoration efforts by killing rust-resistant trees or planted seedlings rather than provide benefits by creating competition-free growing space for future populations. Therefore, mechanical and prescribed fire fuel treatments may be more desirable and manageable than wildfires in the future. Fuel treatments are different from the mechanical cutting and prescribed fire activities mentioned above in that the primary objective of fuel treatments is to reduce fuels instead of whitebark pine restoration. Fuel treatments involve reducing canopy fuels by cutting, masticating, or burning living subalpine fir, spruce, and other shade-tolerant conifer trees and reducing surface fuels by burning or cutting. Reducing fuels in or near stands that contain valuable rust-resistant trees can be an important hedge against losing them to future wildfires. It is critically important that any fuel treatment be also designed in the context of a whitebark pine restoration treatment, and vice versa. This means that the reduction of canopy and surface fuels is a secondary objective. Many contemporary fuel treatments, such as mastication, canopy thinning, and chipping, are not designed with ecological relationships in mind so it is entirely possible that live whitebark pine trees could be cut to reduce fuels. And conversely, restoration treatments that do not also reduce fuels may result in unnecessary losses in seed sources from future wildfires. ***It is very important that any fuel treatment be planned to also be a restoration treatment to be effective from both a fire management and ecosystem restoration perspective***.

To enhance effectiveness of prescribed fire, **fuel augmentation (FA** in Tables 1, 2**)** is the process of changing the fuelbed to facilitate a wider prescribed burning window and a more comprehensive and consistent burn once the fire is ignited. Usually fuel augmentation involves felling the shade-tolerant, fire susceptible competing trees in areas where surface fuels are insufficient to achieve the prescribed burning objective. The red needles and small twigs of the felled trees create additional fine surface fuels that allow prescribed burners to light hotter burns under cooler and moister conditions. This creates a wider temporal burn window thereby allowing fire specialists the ability to ignite a prescribed burn when fuel moistures are higher, such as towards the end of the autumn burning season (Keane and Parsons 2010b). Many seral whitebark pine stands have discontinuous fuelbeds with highly variable fuel loadings that, when burned under typical prescriptions, do not generate enough heat to kill the shade tolerant competitors, so fuel augmentation is often a necessity (Keane and Parsons 2010b).

The successful melding of fuel augmentation and prescribed burning will be an important treatment in the near-term but it may become less important as climate changes become manifest on high elevation landscapes. The treatment that accomplishes the most restoration objectives is often prescribed burning, and to get the best results from the prescribed burns, it is important to augment surface fuels when needed to provide additional control to fire managers. In anticipation of future increases in wildland fire, fuel augmentation and prescribed burning can be used together as fuel reduction treatments to protect rust-resistant pine trees and also as competition removal treatments to improve whitebark pine vigor. Keane and Parsons (2010a) found that those stands that were treated with prescribed fire after fuel augmentation acted as effective fuelbreaks against wildfires that occurred after the prescribed burn. Therefore, the importance of fuel augmentation coupled with prescribed burning will be to condition current stands against future increases in disturbances, primarily fire (through fuel reduction), but also insects and disease (through improved vigor).

Regeneration Treatments

Most proactive, stand-level restoration treatments are designed to remove competition to improve natural regeneration of whitebark pine (Keane and Parsons 2010b). This involves creating stand conditions that facilitate seed caching on the treated site by the Clark's nutcracker. If nutcrackers cache enough seeds, then they may not recover some caches, or snowmelt and spring and summer rains may trigger germination before nutcrackers retrieve the seeds (Tomback 2001). Seedlings from these caches become the whitebark pine forests of the future. Regeneration restoration treatments usually involve removing vegetation from the overstory and understory to create open ground conditions that are used by nutcracker for seed caching (Keane and Arno 2000; Tomback 2001). A variety of mechanical cuttings and prescribed burnings can be used to create conditions that facilitate regeneration, and the most common approaches are group selection harvests and moderately severe prescribed burns (Keane and Parsons 2010a).

Facilitating natural regeneration using management treatments may not be dependable in the near-future, especially with changing climates and continued losses from MPB and WPBR. Relying on natural regeneration is a risky business considering that many areas may have insufficient populations of mature, cone-bearing whitebark pine to sustain viable regeneration. Keane and Parsons (2010a) found little natural whitebark pine regeneration in their treated areas probably because the nutcracker reclaimed most of the cached seed in areas of low seed-producing trees. Even if natural regeneration does occur, the majority of the nutcracker cached seeds may be from whitebark pine trees susceptible to rust. Therefore, most regeneration facilitation treatments should attempt to create suitable ground conditions to allow the successful planting of rust-resistant seedlings. This may be the best option under changing climates, especially in those stands decimated by MPB and WPBR.

Planting treatments

To mitigate the loss of whitebark pine due to climate-mediated changes in disturbance regimes, we must plant those disturbed or treated areas where whitebark pine seed sources have lost cone-producing trees through MPB mortality or WPBR infection with rust-resistant whitebark pine seedlings (Fiedler and McKinney 2014). **Planting (PLANT** in Tables 1, 2**)** is one of the main principles of the range-wide restoration strategy (Keane et al. 2012). Reforestation with rust-resistant seedlings will increase the representation of blister rust-resistant genotypes in the next generation and eventually create resilient whitebark pine forests of diverse age structures that are more likely to withstand frequent fire, MPB outbreaks, and the spread of WPBR. Planting rust-resistant seedlings is recognized as the key management action in the rangewide strategy (Keane et al. 2012)(Keane and others 2012). Sowing seeds from rust-resistant sources directly in treated or burned areas, if shown to be efficacious, may be a cost-efficient alternative to growing seedlings and planting them. Areas with declining whitebark pine seed sources are unlikely to produce enough seeds to attract and support nutcrackers, so natural seed dispersal is unlikely (McKinney et al. 2009). And, because blister rust is at the northern limit of whitebark pine's range, as well as the upper elevational limits, both important climate change fronts, seedlings from rust-resistant parent trees should be planted at both limits. Most other restoration actions will be ineffective without the planting of rust-resistant seedlings.

We have several suggestions for planting seedlings to mitigate the effects of climate change and ensure high seedling survival. First, planting probably should be prioritized for the higher portions of whitebark pine seral sites based on results of our simulation experiment that found sapling survival highest in the colder portions of whitebark pine's range (Keane et al. 2016). Given the high costs of growing rust-resistant seedlings and planting of them in remote settings, planting should start at the highest regions in burned areas where they are most likely to survive in the future, and then planting should progress downwards in elevation. Second, seedlings should be planted in microsites that best mitigate harsh conditions and provide shade or wind protection (McCaughey et al. 2009). For example, they should be planted on the side of a rock, stump, or other object that provides some protection. Microsites may moderate seasonally arid conditions when the planted seedling is most susceptible to drought effects, or protect against hard frosts, deep snow packs, prolonged insolation, drought, and soil erosion during the critical time of seedling establishment (Scott and McCaughey 2006). Since snags eventually fall, planting next to snags should be avoided, but planting next to stumps often provides good protection. If no favorable microsites for planting exist, then we suggest that planting crews be instructed to create the microsite using a log, rock, or wood stake, or other protection device. Next, planting sites may need to be selected based on whether they might contain important mycorrhizae needed to ensure seedling survival (Lonergan et al. 2013). Seedlings planted in proximity to sapling or mature whitebark pine trees, or perhaps near *Vaccinium* spp. Shrubs, regeneration have a chance to be colonized by the appropriate mycorrhizae (Mohatt et al. 2008, Perkins 2015). Moreover, it may be advantageous to wait for undergrowth vegetation, particularly shrubs, to develop before planting whitebark pine seedlings on burned sites, although this could require a number of years for extreme sites. There may be excessive erosion and soil movement during the years directly after a burn that may dislodge planted seedlings, and undergrowth shrubs may provide partial shade that is favorable to seedling survival (Tomback and others 2011b). Perhaps waiting until shrub and herbaceous plants have re-established before extensive planting is implemented may be more effective, except when beargrass (*Xerophyllum tenax*) is present (Izlar 2007, McCaughey et al. 2009).

Special attention should be given to the planting guidelines of McCaughey et al. (2009) and Scott and McCaughey (2006) in the future. Large, hardy seedlings with well-developed root systems will survive best in the highly variable climates of the future. Seedlings should be planted in competition-free environments so that shading effects are minimized and the seedling can grow its best to be more resilient. However, some partial shade and physical protection may enhance survival by using shade cards and planning site mitigation, such as placing logs or rocks around the seedling. Moist soils will be critical for high survival after planting seedlings. Managers are now waiting until the fall to plant whitebark pine seedlings to avoid summer droughts, so it might be more effective to also wait until autumn rains have wet the soils before planting, especially with future warmer and drier climates.

For the last decade, sowing seeds ("direct sowing") from potential or known rust-resistant trees, as opposed to planting seedlings, has been explored as a more cost-efficient option that would enable restoration in remote terrain ((Schwandt et al. 2011). In some landscapes, germination rates and seedling survival may be high enough for sowing to be a viable and more economical alternative.

Guidelines and Best Practices

Our set of best practices and fire management guidelines was specifically designed to be implemented in lands with the COTC ecosystem, but we fully recognize that each land management agency has its own set of policies and protocols for implementing a fire management plan. As a result, we have written these guidelines in a tabular and generalized format that can easily be expanded, modified, and amended at a later date. There are two tables below that describe the recommended best fire management practices for the COTC along with any associated actions that fire or land managers might want to employ before and after a wildfire that may reduce the impacts of the wildfire and restore whitebark pine ecosystems.

The table recognizes two site types: sites where whitebark pine is seral to subalpine fir, spruce, and mountain hemlock (**SERAL**) and sites where whitebark pine is the indicated climax and all other competitors do not achieve dominance (**CLIMAX**). Several types of stand conditions are also included in Table 1: recently burned or treated stands in whitebark pine habitat (**BURNED**), early seral (seedling, sapling) stands dominated by whitebark pine (**EARLY**), mid-seral (pole, mature) stands dominated by whitebark pine (**MID**), late seral stands dominated by the competitors of whitebark pine on lands that could support whitebark pine (**LATE**), stands of any seral stage that are dominated by the competitors of whitebark pine such as fir, spruce, and hemlock (**FIR**), stands with high whitebark pine mortality (>70%) and evidence of rust-resistant, cone-producing whitebark pine trees (**MORT**), stands that have recently (<10 yr since treatment) been treated (**TREAT**), and all stand conditions for seral or climax sites (ALL).

Four columns in Table 1 denote fire management and restoration actions that may facilitate the maintenance of whitebark pine on COTC landscapes. First is the best fire management practices for the COTC. There are three options for fire management on whitebark pine areas: full suppression (FS), partial suppression, and allowing wildfires to burn under an acceptable set of conditions (WFU for wildland fire use) (Table 2). The next column are the prescribed fire management actions that can be implemented in advance of a wildfire to improve, mitigate, or protect whitebark pine ecosystems from the effects of wildfire. The column after that are the mechanical treatments that can be taken to enhance, protect, or mitigate effects of wildfire. Table 2 contains all the details associated with these fire management, prescribed fire, and mechanical actions. The last column are any suggestions or recommendations when implementing any of these actions on whitebark pine landscapes.

Table 1. The set of best fire management practices, associated prescribed fire treatments, and companion restoration treatments before and after the wildfire for two site types (climax, seral), and several landscape or stand conditions. Best Fire Management Practices, Prescribed fire actions, and Companion mechanical restoration actions are listed in order of preference and their acronyms are defined and detailed in Table 2 along with a complete description of other concerns and the definitions of the acronyms.

Site type	Landscape or Stand condition	Best fire management practices	Possible prescribed burning actions before fire	Possible companion mechanical restoration actions before fire	Possible restoration actions after wildfire or treatment	Other Concerns (Notes)
SERAL	BURNED	PS, WFU	None	None	PLANT, MON	RR,PT
	EARLY	PS, WFU	None	SFT, DAY	PLANT, MON	RR,PT
	MID	PS, WFU	PFLI	THIN, FA	PLANT, MON	FR,RR,PT,PILE
	LATE	WFU	PFMI, PFLI, PFHI	THIN, FA, SEL, NO	PLANT, MON	FR,RR, PT,PILE
	FIR	WFU	PFHI, PFMI	NO, SEL	PLANT, MON	FR,RR, PT,PILE
	MORT	PS, FS, WFU	PFLI, PFMI	SEL, NO, THIN, SFT, DAY, FA	PLANT, MON	FR,RR, PT,PILE
	TREAT	FS, WFU	None	None	MON	
CLIMAX	ALL	PS, WFU	None	SFT, DAY	PLANT, MON	RR, PT

Site type:
CLIMAX-Areas where whitebark pine is the major climax species
SERAL-Areas where whitebark pine is seral to other shade-tolerant conifers

Stand condition:
BURNED- Recently burned or treated stands in whitebark pine habitat
EARLY- Early seral (seedling, sapling) stands dominated by whitebark pine in seral site type
MID- Mid-seral (pole, mature) stands dominated by whitebark pine in seral site type
LATE- Late seral stands dominated by the competitors of whitebark pine on lands that could support whitebark pine in seral site type and there are still living whitebark pine in stand.
FIR- Any early or mid-seral stand that is dominated by the competitors of whitebark pine
MORT- Any stand in in the seral site type with high whitebark pine mortality (>70%) **and** evidence of rust-resistant, cone-producing whitebark pine trees
TREAT- previously treated stands or landscapes that have received a fuel treatment or restoration action
ALL- Any stand on whitebark pine climax sites of any seral stage

Table 2. The list of fire management, prescribed fire, and mechanical treatment restoration actions for creating the best fire management practices for whitebark pine ecosystems.

	Action	Description	Restoration Objective
		Fire management actions	
FS	Full suppression	Fight all fires in the area; emphasize initial attack	Protect living whitebark pine trees, especially those trees that are known to be rust-resistant or have the potential to be rust-resistant by eliminating fire; Protect early seral stands dominated by whitebark pine to allow future seed production; accept minor losses from retardant drop damage
PS	Partial suppression	Fight all fires in the area and emphasize initial attack BUT do not use aircraft retardant drops because they may harm valuable trees	Protect living whitebark pine trees, especially those trees that are known to be rust-resistant or have the potential to be rust-resistant by eliminating fire; Protect early seral stands dominated by whitebark pine to allow future seed production
WFU	Wildland fire use	Allow fires to burn under prescribed conditions	Implement a restoration treatment that mimics natural processes: see R1 if WFU fire is low intensity, see R2 if WFU fire is moderate intensity and R3 if high intensity WFU fire
		Prescribed fire actions before the wildfire event	
PFLI	Low intensity prescribed fire	Implement a controlled burn in a treatment unit using prescribed fire to mimic effects of a non-lethal surface fire; may be paired with a fuel augmentation treatment (R)	Ensure survival of living, cone-producing whitebark pine trees while killing all sizes of its other competitors thereby maintaining cone production and slowing successional advance
PFMI	Moderate intensity prescribed fire	Implement a controlled burn in a treatment using prescribed fire to mimic effects of a mixed severity fire; may be paired with a fuel augmentation treatment (R)	Create caching or planting sites for whitebark pine regeneration; remove or reduce competitors of whitebark pine; mimic natural fire processes
PFHI	High intensity prescribed fire	Implement a controlled burn in a treatment using prescribed fire to mimic effects of a stand-replacement severity fire; may be paired with a fuel augmentation treatment (R)	Create caching or planting sites for whitebark pine regeneration; remove or reduce competitors of whitebark pine; mimic natural fire processes; create large burned areas where only the bird-dispersed whitebark pine can regenerate

Mechanical treatment restoration actions before or after the wildfire			
THIN	Thinning	Mechanically cut trees that impede growth and vitality of whitebark pine in both overstory and understory; attempt to mimic a non-lethal surface fire regime	Reduce whitebark pine competition while also reducing canopy fuels to decrease potential for crown fire; create thrifty living cone-producing whitebark pine trees, especially in stands where rust-resistance may be high
SEL	Selection cutting	Mechanically cut competing trees in clumps to improve whitebark pine tree health and vigor while also mimicking a mixed severity fire regime	Create whitebark pine seed caching habitat for the Clark's nutcracker; Reduce whitebark pine competition while also reducing canopy fuels to decrease potential for crown fire; create thrifty living cone-producing whitebark pine trees, especially in stands where rust-resistance may be high
NO	Nutcracker openings	Cutting all trees but whitebark pine in patches of 10-30 ha to mimic mixed severity fire or patches greater than 50 ha to mimic stand-replacement fires	Create whitebark pine seed caching habitat for the Clark's nutcracker; Reduce whitebark pine competition to improve regeneration and living tree vigor while also reducing canopy fuels to decrease potential for crown fire; create thrifty living cone-producing whitebark pine trees, especially in stands where rust-resistance may be high
FA	Fuel Augmentation	Add fine woody and foliar fuel to the surface fuelbed by cutting trees that are not whitebark pine in a pattern to facilitate fire spread	Cut trees of whitebark pine competitors and arrange the fallen trees so they are distant from living whitebark pine while attempting to create a continuous surface fuelbed and reduce canopy fuels
PLANT	Plant seedlings or seed	Plant rust-resistant seedlings in treatment units where competition has been removed, or plant in recently burned areas where tree and grass competition is minimal	Ensure disturbed stands will regenerate to whitebark pine, and hopefully to rust-resistant whitebark pine; augment the natural dispersal process to ensure whitebark pine regeneration; provide whitebark pine regeneration in those areas where whitebark pine mortality is high
DAY	Daylighting	Remove competition and fuels around putative or phenotypic rust-resistant whitebark pine trees at a diameter equal to canopy height	Improve the vigor of living whitebark pine trees; reduce potential for mountain pine beetle infection by putting more sunlight on bole; reduce WPBR infection by decreasing local humidity; reduce fire hazard by removing canopy and surface fuels

SFT	Spot fuel treatment	Reduce surface and canopy fuels around individual whitebark pine trees to lessen the potential for fire-caused mortality by reducing behavior (lower intensity, slower spread rate)	Protect living whitebark pine trees from wildfire, especially those trees that are known to be rust-resistant or have the potential to be rust-resistant
MON	Monitor	Monitor the effects of the treatment(s) or wildfire	Document effects of treatment or wildfire to improve management strategies
		Important Notes	
RR	Rust-resistance	Plant only rust-resistant seedlings; plant in places that are rich in mycorrhizae (near *Vaccinium* spp); plant only in places that lack any tree competition with the seedlings (all of whitebark pine's associates will outgrow the species)	Follow all guidelines on planting including those detailed in McCaughey et al, (2009), Scott and McCaughey (2006); plant in spacings that are about 20 ft by 20 ft but be sure to adjust for potential losses from WPBR;
PT	Plus-trees	Protect all identified plus trees first then protect all trees that have the obvious potential to be rust resistant	Retain rust-resistant trees on the landscape for pollination and cone-collection
FR	Frost	Should probably wait for the first hard frost in the fall before attempting a prescribed burn; shrubs and herbs will carry the fire in most circumstances	If in doubt, take fuel moisture measurements of herb and shrub to see if dry enough to burn;
PILE	Piles	If mechanical treatments result in slash piles, try to remove or burn the piles relatively quickly	Prevent Ips spp. Caused pine mortality; reduce fuel hazard; allow for greater nutcracker caching

Appendices

Appendix 1. Sources for blister rust resistant seedlings.

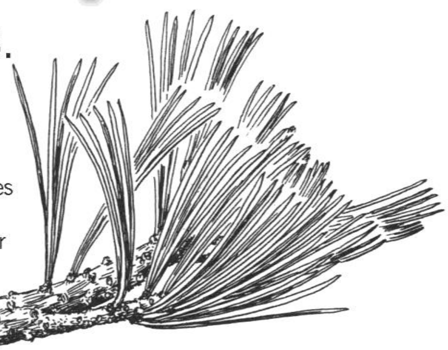
Facility	Contact	Regional Specialists
Coeur d'Alene Nursery, US Forest Service	208-765-7375	Mary Francis Mahalovich, 208-883-2350
Dorena Genetic Resource Center, US Forest Service	503-808-2468	Richard Sniezko, 541-767-5716
Kalamalka Research Station, BC Ministry of Forests	250-260-4755	Michael Murray, 250-354-6852 Ward Strong, 250-260-4763

Appendix 2. Poster recommended for posting in Fire Staff offices, camps, and other places where field and fire crews can read.

Needles of five, keep it alive!

Please do not cut WHITEBARK PINES.

If a tree's needles grow in clusters of five, leave it to grow!



Whitebark pines live in the mountains, often in areas too harsh for any other tree. More than 100 kinds of living things depend on these special pines, including bears and many bird species. People love whitebark pines for their beauty and strength, and we also need them because they trap snow in the high country, slowing spring runoff and helping provide water to the valleys in summer.

But whitebark pines are in trouble. Many whitebark forests now contain more dead pines than living ones.

- Blister rust, a non-native fungus, weakens the trees, reduces cone production, and eventually causes death.
- Whitebarks are also killed by bark beetles, and beetle epidemics may increase with global climate change.
- Wildfires may kill whitebark pines, although burned areas are good habitat for seedlings. Careful management of fire is essential.

So remember: *If it has five, let's keep it alive!*

For more information and to learn how you can help,
visit the Whitebark Pine Ecosystem Foundation at www.whitebarkfound.org.

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