The Importance of Wilderness to Whitebark Pine Research and Management

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Abstract—Whitebark pine is a keystone species in upper subalpine forests of the northern Rocky Mountains, Cascades, and Sierra Nevada that has been declining because of recent mountain pine beetle and exotic blister rust epidemics, coupled with advancing succession resulting from fire exclusion. Whitebark pine and Wilderness have a mutually beneficial relationship because 1) half of whitebark pine's range is in wilderness, 2) many wildlife species depend on whitebark pine ecosystems, 3) whitebark pine forests have high recreation value, and 4) whitebark pine landscapes contain unique ecological processes. Wilderness has not escaped the ravages of beetle, rust and fire exclusion, so restoration of these ecosystems may be warranted in some areas. The best wilderness restoration tool appears to be prescribed fires, especially management-ignited burns. This paper discusses whitebark pine ecology and the importance of the species to wilderness, and presents restoration treatments and management alternatives for these remote settings.

Whitebark pine (*Pinus albicaulis)* is an important tree species in many upper subalpine forests of the northern Rocky Mountains, Sierra Nevada and Cascades in the United States and Canada (Arno and Hoff 1990). The species produces large seeds that are highly prized by many animal species, and its forests provide critical wildlife habitat and watershed protection (Hutchins and Lanner 1982; Hann 1990). Healthy stands of whitebark pine can produce over 100 kg ha^{-1} of seed in good cone crop years (Forcella and Weaver 1980). One bird, the Clark's Nutcracker (*Nucifraga columbiana*), has evolved a mutualistic relationship with whitebark pine in which it is the sole vector of seed dispersal (Tomback and others 1990). Whitebark pine forests have recently been declining in the northern portions of its range because of recent mountain pine beetle (*Dentroctonous ponderosae*) and blister rust (*Cronartium ribicola*) epidemics, and advancing succession from more than 70 years of fire exclusion (Keane and Arno 1993; Kendall and Arno 1990). Recent research efforts have been investigating techniques to restore ecosystem health and return fire processes and historical stand characteristics to the declining landscapes (Keane and Arno 1996). However, many whitebark pine stands occur in wilderness areas, which may preclude some proactive restoration techniques.

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Many wilderness areas encompass the same high mountain settings where whitebark pine ecosystems are often found (Cole 1990). In fact, many whitebark pine forests (over 45 percent) occur in wilderness areas or national parks. Wilderness areas will play a critical role in the conservation of this vital species. Some have a semblance of an intact fire regime that would provide critical baseline or reference data for whitebark pine stand and landscape dynamics at large spatial and temporal scales. Unfortunately, many wilderness areas are also experiencing severe whitebark pine declines, and restoration projects may be difficult to implement because of inaccessibility, special regulations and adverse sociopolitical attitudes (Czech 1996). This paper summarizes whitebark pine ecology, presents the importance of wilderness areas to whitebark pine ecosystems and vice versa, and discusses possible restoration treatments and management alternatives for these remote settings.

Background

Whitebark Pine Ecology

Whitebark pine is a long-lived, seral tree of moderate shade tolerance (Minore 1979). Although it can live well over 400 years (the oldest individual is more than 1300 years), it is eventually replaced, in the absence of fire, primarily by the shade-tolerant subalpine fir (*Abies lasiocarpa*), spruce (*Picea engelmannii*), and mountain hemlock (*Tsuga mertensiana*) in the mesic parts of its range (Arno and Hoff 1990; Keane, in press). Whitebark pine also competes with lodgepole pine *(Pinus contorta*) during early successional stages in the lower portions of its elevational range (Arno and others 1993; Mattson and Reinhart 1990). It can take anywhere from 50 to 250 years for subalpine fir to replace whitebark pine in the overstory depending on the local environment and previous fire history (Keane, in press).

Whitebark pine comprises about 10-15 percent of the forested landscape in the upper subalpine zone of the northern Rocky Mountains (Arno and Hoff 1990). Although this species has limited use as a commercial timber species because of its diminutive stature, gnarled growth form and remote setting, it produces seeds that are highly prized for food by many species of wildlife, including the threatened grizzly bear (*Ursus arctos horribilis*) (Mattson and others 1991), red squirrel (*Tamiasciurus hudsonicus*) (Ferner 1974), and Clark's nutcracker (*Nucifraga columbiana*) (Tomback 1989). The Clark's nutcracker plays a critical role in the whitebark pine regeneration process because this bird is essentially the only dispersal vector for the heavy, wingless seed (Tomback 1989; Tomback 1998). Whitebark pine also protects snowpack in high-elevation watersheds and delays snowmelt, providing high quality water to valleys below throughout the summer (Arno and Hoff 1990; Hann 1990).

In general, whitebark pine is found in two types of high mountain environments. Most common are upper subalpine sites where whitebark pine is the major seral species and it is successionally replaced by the shade-tolerant fir, spruce or mountain hemlock, depending on geographic region. These sites support upright, closed-canopy forests but occur at the lower transition to timberline, just above or overlapping with the elevational limit of lodgepole pine (Arno and Weaver 1990; Pfister and others 1977). Sites where whitebark pine is the indicated climax species (that is, it is the only tree species able to successfully reproduce and mature) are found at lower timberline on relatively dry, cold slopes, where trees often occur in elfin forests, clusters, groves or tree islands (Arno 1986; Arno and Weaver 1990; Steele and others 1983). Subalpine fir can occur on these sites, but as scattered individuals with truncated growth forms (Arno and Hoff 1990; Arno and Weaver 1990; Cooper and others 1991; Pfister and others 1977). Whitebark pine can also exist as krummholz on alpine sites (Arno and Hoff 1990; Tomback 1989), and as a minor seral in lower subalpine sites (Cooper and others 1991; Pfister and others 1977), but these sites are not discussed here.

Fire Ecology

Three types of fires define fire regimes in whitebark pine forests (Arno and Hoff 1990; Morgan and others 1994). Some high, dry whitebark pine stands experience recurrent nonlethal underburns because of sparse fuel loadings, but these are mostly confined to the southern parts of the species range in the Rocky Mountains, and represent only a small portion of existing whitebark pine forests (less than 10 percent) (Morgan and others 1994). Most of these areas are still disease-free and within the fire rotation because of the inhospitable conditions for the rust infection and the long fire-return intervals.

The more common, mixed-severity fire regime is characterized by fires of different severities in space and time, creating complex patterns of tree survival and mortality on the landscape. Mixed severity fires can occur at 60- to 300-year intervals (Arno and Hoff 1990; Morgan and others 1994). Individual fires can be surface fires with differential mortality (underburns), stand-replacement fires, and most often, fires that contain elements of both (Morgan and others 1994). Sometimes fire burns in sparse ground fuels at low severities, killing the smallest trees and the most fire-susceptible overstory species, often subalpine fir. Severities increase if the fire enters areas with high fuel loads or if the fire gains entrance into tree crowns due to increasing winds, thereby creating patches of high fire-killed mortality (Lasko 1990). Burned patches are often 1 to 30 ha in size, depending on topography and fuels, and these openings provide important caching habitat for the Clark's nutcracker (Norment 1991; Tomback and others 1990).

Many whitebark pine forests in northwestern Montana, northern Idaho and the Cascades originated from large, stand-replacement fires that occurred at long time intervals (greater than 250 years) (Arno 1986; Keane and others 1994; Morgan and others 1994). Stand-replacement fires also occurred within mixed-severity fire regimes, but as infrequent events. These fires are usually wind-driven and often originate in lower, forested stands (Murray and others 1998).

Whitebark pine benefits from wildland fire because it is more capable of surviving and regenerating after fire than its associated shade-tolerant trees (Arno and Hoff 1990). Whitebark pine is able to survive low severity fires better than its competitors because it has thicker bark, thinner crowns and deeper roots. It readily recolonizes large, stand-replacement burns because its seeds are transported great distances by Clark's nutcrackers. Nutcrackers can disperse whitebark pine seeds up to 100 times farther than wind can disperse seeds of subalpine fir and spruce (McCaughey and others 1985; Tomback and others 1990; Tomback and others 1993). Essentially all whitebark pine regeneration comes from unclaimed nutcracker caches, where seeds eventually germinate and grow into seedlings (Keane and others 1990). Nutcrackers prefer open sites with many visual cues for seed caching, much like the burned stands after a mixed or stand-replacement fire (McCaughey and Weaver 1990; Sund and others 1991; Tomback 1989; Tomback and others 1990; Tomback 1998). Nutcrackers will cache seed in beetle- or rusk-killed stands, but whitebark pine germinants usually will not survive in the shaded subalpine fir understory. Burned patches can be any size for nutcracker caching, but Norment (1991) found frequent caching in patches 1 to 30 ha, about the same size as patches created by mixed-severity burns.

Whitebark Pine Decline

Whitebark pine is declining in areas of the northern Rocky Mountains and Cascades because of several native and exotic processes interacting at different spatial and temporal scales (Arno 1986; Ciesla and Furniss 1986; Keane and Arno 1993; Kendall and Arno 1990). The successional replacement of whitebark pine by subalpine fir and spruce is a process that, prior to 1930, was usually interrupted by naturally occurring fires (Arno and Hoff 1990; Morgan and others 1994). However, 60+ years of fire exclusion have allowed fir and spruce to become dominant in many forests historically dominated by whitebark pine (Arno 1986; Keane and others 1994). The cumulative effects of fire exclusion in these long fire-return interval, high-elevation landscapes would probably not be readily apparent as yet if it had not been for a native pine beetle and an exotic disease.

Extensive mountain pine beetle epidemics during the 1930's and 1940's killed many whitebark pine trees in western Montana and central Idaho (Baker and others 1971). Although this epidemic was extensive and deadly, the whitebark pine ecosystem could have easily recovered if fires had been allowed to burn the beetle-killed landscape (Perkins and Swetnam 1996). Meanwhile, white pine blister rust, an exotic disease brought over from Europe around 1910, started killing whitebark pine forests as early as the 1930's in northwestern Montana, northern and central Idaho and the Cascades (Arno and Hoff 1990; Hoff and others 1980; Keane and Arno 1993; Kendall and Arno 1990). Both the rust and beetle kill mature, cone-bearing trees thereby accelerating the successional replacement of whitebark pine to the more shade-tolerant fir and spruce. Thus, the killing of whitebark pine by rust and beetles, coupled with the lack of fire as a recycling agent, has caused a major shift in landscape composition and structure from one of pine to fir and spruce. Blister rust and beetle have accelerated succession to subalpine fir by killing mature whitebark pine, thereby truncating an important successional community.

Wilderness and Whitebark Pine

Geography

Whitebark pine ecosystems are important to Pacific Northwest wilderness ecology because they comprise a large component of many high-elevation wilderness areas (Cole 1990). Previous methods used to estimate the extent of whitebark pine in wilderness areas were confounded by inadequate data and small-scale range maps of the species (Arno and Hoff 1990). We used several digital spatial products, statistical analysis and GIS (Geographic Information Systems) techniques to compute the potential and existing range of whitebark pine in wilderness and roadless areas based on knowledge of local whitebark pine topographic relationships. First, we digitized the range of whitebark pine into a GIS from maps of Arno and Hoff (1990) and Little (1971) that coarsely describe the entire range of whitebark pine within the United States. We called this map the **Whitebark Pine Range Map** (figure 1a). This map has many limitations because it was broadly drawn from low resolution maps.

We next imported all the Western State Gap data layers of vegetation created from satellite imagery into the whitebark pine GIS to describe the current distribution of existing vegetation in the western United States (Redmond and Prather 1996, for example). These maps were merged then refined to accurately and consistently characterize mid scale vegetation distribution in categories useful to research and management (Keane and others 1996). We then selected only those polygons that were classified to whitebark pine, or a mixed conifer cover type with whitebark pine dominant, to describe the current distribution of whitebark pine cover types. This map is called the **Existing Whitebark Pine Map** (figure 1b).

A third map, called the **Potential Whitebark Pine Map** (figure 1c), depicts all areas having the potential to support whitebark pine and more narrowly defines the range of the species to elevational limits. First, all lands classified as barren, rock or water identified in the GAP maps were removed from the analysis. The elevational limits of whitebark pine were then defined from the following two regression equations:

$$LEL = 2446.0856 - 0.001321(NOC) \quad R^2 = 0.68, df = 35, SE = 150.21$$
$$UEL = 2838.8867 - 0.001057(NOC) \quad R^2 = 0.87, df = 26, SE = 67.60$$

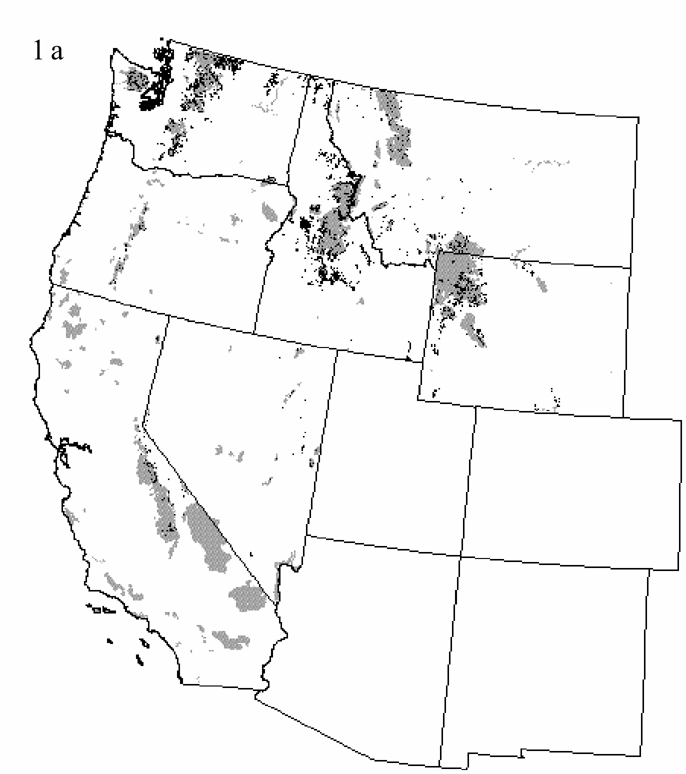
Where LEL is the lower elevational limit (m), UEL is the upper elevational limit (m), and NOC is the Lambert-Azimuthal North Coordinate (km) from the GIS projection.

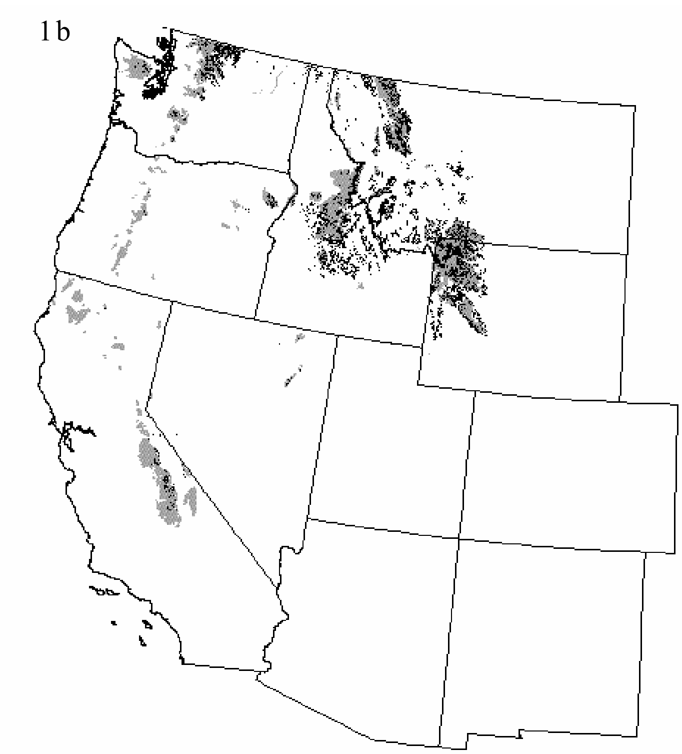
These equations were constructed from available field data (Keane and others 1994), personal observations of whitebark pine elevational limits across the northern Rockies and Cascades (Arno and Hoff 1990), and an extensive review of the literature (see figure 2) (Arno 1979; Cooper and others 1991; Pfister and others 1977; Steele and others 1983; Weaver and Dale 1974). Both equations were coded into the GIS to produce a layer that defined all lands that could potentially support whitebark pine. This layer was adjusted to exclude those high-elevation areas outside whitebark pine's geographical range using Arno and Hoff's (1990) map. The final map, shown in figure 1c, provides a more accurate, coarse-scale habitat model for whitebark pine than the Whitebark Pine Range Map. This map is somewhat conservative since Arno and others (1993) found that, historically, whitebark pine was a dominant overstory species hundreds of meters below its current documented distribution.

We then performed the GIS analysis by overlaying land ownership, a layer already built by the USDA Forest Service, with existing and potential (that is, range and regression maps) whitebark pine lands to determine the geographical importance of wilderness to whitebark pine ecosystems (table 1). We stratified potential and existing whitebark pine coverage by land ownership within the states that contained whitebark pine and found that over 47 percent of all potential whitebark pine habitat and 49 percent of all existing whitebark pine stands occur within wilderness and national parks (table 1). This analysis also revealed that about 80 percent of all lands supporting or having the potential to support whitebark pine are managed by the Forest Service in states containing whitebark pine. Over 95 percent of whitebark pine habitat occurs on federal lands with the remainder on state and private lands. The three largest wilderness settings in the western United States, the Bob Marshall Wilderness Complex, the Selway-Bitterroot-Frank Church Wilderness Complex and Yellowstone National Park, have 49, 23 and 47 percent of their lands in potential whitebark pine habitat, respectively (Keane and others 1994). Moreover, nearly all whitebark pine lands are on publicly managed lands allowing for a comprehensive restoration policy across all land management agencies. With nearly half of all current and potential whitebark pine lands in wilderness, wilderness management will inevitably play a crucial role in the perpetuation of this threatened ecosystem.

Ecosystem Processes and Values

Wilderness areas are important reserves for whitebark pine because the adverse effects of 60+ years of fire exclusion have not yet been manifest in portions of some wilderness areas for several reasons. First, most wilderness areas contain high mountain ecosystems where fire intervals are longer than those characterizing lower elevation forests such as ponderosa pine. Therefore, many portions of mountainous wilderness may still be within a natural fire rotation if evaluated at the stand-level. However, if the entire wilderness landscape were analyzed, an unusually large proportion would be in late seral stages dominated by shade-tolerant trees compared to historical landscapes, which had high proportions of young seral forests, and there would be a preponderance of multistoried stand structures, symptomatic of fire exclusion impacts (Habeck 1970; Habeck 1985; Rogeau 1996). Second, some fires have been allowed to burn in some of wilderness areas because of active fire management programs. Beginning in 1973, the Selway-Bitterroot Wilderness has had one of the most active wilderness fire programs in the western United States. Comparing this program to historical fire regimes, Brown and others (1994) found that many areas in the Selway-Bitterroot Wilderness Area were within the historical fire return interval, except





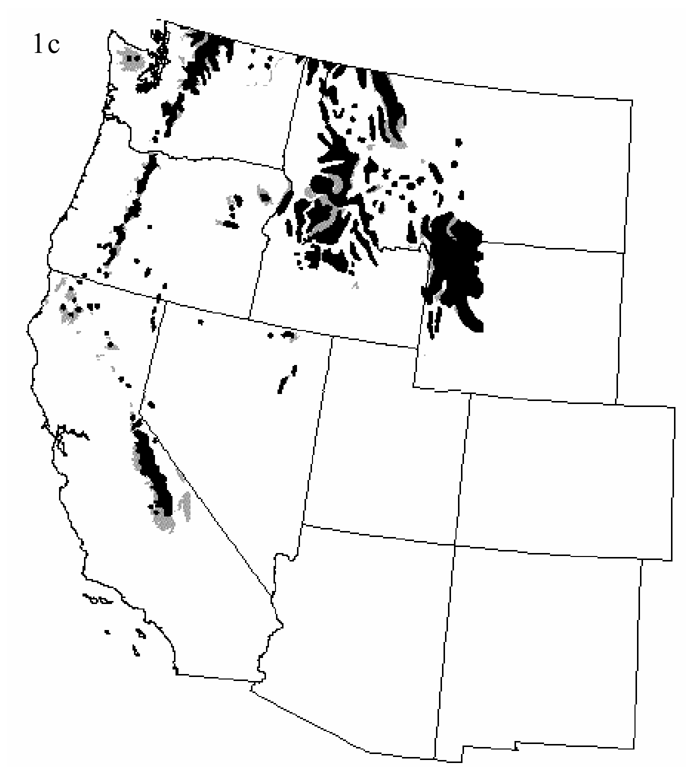


Figure 1—Extent of whitebark pine in the United States. Areas in black are where whitebark pine can be found, and areas in grey are Wilderness areas and National Parks. The areas in black were derived from (a) Whitebark Pine Range Map or potential range of whitebark pine from range map in Arno and Hoff (1990), (b) Potential Whitebark Pine Map or the areas that have the potential to support whitebark pine based on regression analysis, and (c) Existing Whitebark Pine Map, or the extent of current whitebark pine coverage from western state GAP maps.

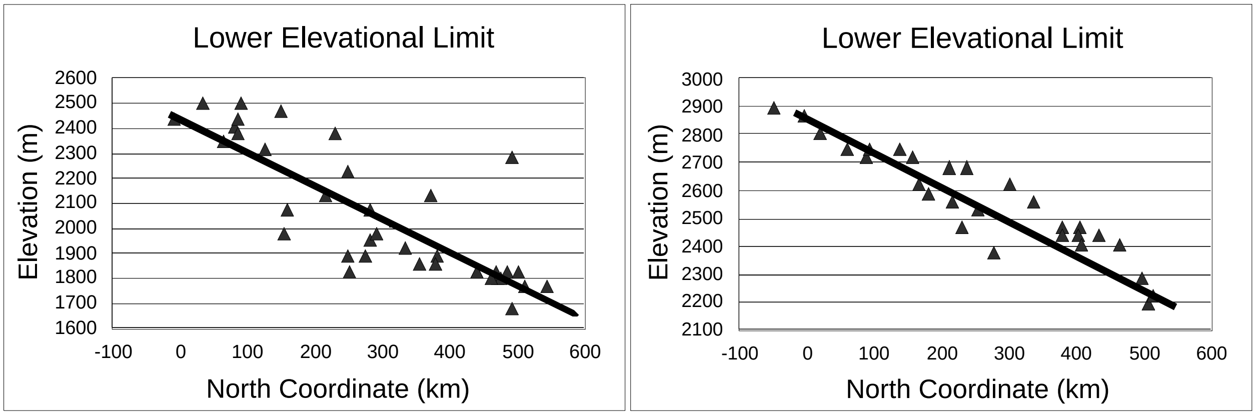


Figure 2—Scattergraphs of the lower (left) and upper (right) elevational livit of whitebark pine with the U.S.A. Albers North Coordinate. Regression lines are shown.

for ponderosa pine and whitebark pine ecosystems. Approximately 4,500 ha per year have been burning in the Bob Marshall Wilderness Area since 1980, albeit most were burned in two of those 15 years. Wilderness areas with intact fire regimes provide ideal laboratories to investigate large-scale ecosystem dynamics of whitebark pine.

The whitebark pine ecosystem is especially important to the wilderness recreational experience because its majestic form and picturesque surroundings are aesthetically pleasing to most wilderness travelers (Cole 1990; McCool and Friedman, in press). Many backpackers make whitebark pine forests their destination because they are typically open and park-like. The vistas are especially scenic because the forests are at high elevations where the wilderness traveler can view an entire wilderness landscape. Cole (1977) mentions that 46 percent of trail miles and 78 percent of campsites are in upper subalpine forest types. Many people cannot readily visit remote and inaccessible whitebark pine forests because it requires a physically demanding hike to reach these scenic ecosystems. Therefore, when they do visit, they are often captivated by the extraordinary beauty of the tree, the uniqueness of the surrounding stand, and the rugged, high mountain landscape. And since whitebark pine landscapes are diverse and open, it is relatively easy to hike off-trail and explore (Cole 1990). McCool and Friedman (in press) speculate on how the loss of whitebark pine in high mountain settings may detract from the wilderness experience. Therefore, these stately trees are not only crucial to the upper subalpine ecosystem, they also are important to wilderness beauty and the wilderness experience.

Whitebark pine ecosystems provide important food and habitat for many plant and animal species. Hutchins and Lanner (1982) documented over 110 wildlife species that utilize whitebark pine seed crops. In good cone years, whitebark pine seed comprises over 40 percent of the annual diet of Yellowstone grizzly bears (Mattson and others 1991). Nutcrackers and squirrels ultimately depend on whitebark pine seed to survive winter and spring food shortages (Mattson and Reinhart 1990; Tomback 1989). Open whitebark pine forests benefit many wildlife species because additional light increases undergrowth forage quality and berry production (Kendall and Arno 1990).

Table 1—Potential and existing whitebark pine extents (1000 x km^2) stratified by various land ownership and management categories (numbers in parenthesis are percent of total). These numbers are summarized for those States containing whitebark pine.

Land ownership	Existing whitebark pine map (state GAP maps)	Potential whitebark pine map (regression approach)	Whitebark pine range map Arno&Hoff 1990
Wilderness Areas and National Parks	4.6 (49)	27.1 (47)	69.3 (42)
National Forests	7.7 (82)	46.9 (81)	126.1 (76)
National Parks only	1.4 (15)	7.4 (13)	20.7 (13)
All Public lands	9.4 (99)	56.5 (98)	154.3 (94)
Private lands	0.1 (1)	1.1 (2)	10.6 (6)
Total	9.5 (100)	57.6 (100)	164.9 (100)

Wilderness Restoration: A Management Paradox?

Wilderness Whitebark Pine Status

Wilderness areas are not immune to the devastating effects of the exotic blister rust disease because of their remote settings or protected status. Many wilderness and roadless areas in the northern Rockies and Cascades containing five-needled pines have been experiencing rust-caused mortality for a half century or longer (Hoff and Hagle 1990). Blister rust spores are highly mobile, especially the wind-borne aeciospores, and can spread tens to hundreds of kilometers in a season, depending on winds and precipitation. Moreover, the rust will kill most whitebark pine trees regardless of tree vigor, ecosystem health or distance from humans, given enough time. Therefore, wilderness areas are no better protected from blister rust than any other high mountain landscape (Keane and others 1994; Kendall and Arno 1990).

There is little doubt that many wilderness areas are experiencing the same declines in whitebark pine as non-wilderness lands. Kendall and Arno (1990) estimate that over 90 percent of Glacier National Park's whitebark pine has died as a result of blister rust. Keane and others (1994) calculated that about 40 percent of the whitebark pine forests in the Bob Marshall Wilderness Complex has experienced over 50 percent rust-caused mortality. Keane and Arno (1993) remeasured 20-year old plots and found that whitebark pine stands in western Montana around the Selway-Bitterroot Wilderness Area have lost from 40 to 90 percent of whitebark pine basal area to blister rust and advancing succession. Smith and Hoffman (1998) also measured severe declines in both limber and whitebark pine in the southern parts of Idaho in roadless settings.

Unquestionably, human actions have directly (fire exclusion) and indirectly (rust epidemics) contributed to the decline of whitebark pine in and around wilderness areas. Even in the Selway-Bitterroot Wilderness Area, the annual area burned in whitebark pine forests is still less than 38 percent of the historical average (Brown and others 1994). Small wilderness areas atop isolated mountain ranges are especially vulnerable to fire suppression impacts because they are usually surrounded by private or public lands where fire suppression is practiced, so fire managers cannot allow fires to burn into the upper subalpine forests (Husari 1995; Murray and others 1998). As a result, the thin veil of pristineness has long been removed from many high mountain wilderness settings and it is doubtful the perceived pristine conditions will ever return. Fire exclusion has affected nearly every wilderness area in the western United States, and suppression of fires will undoubtedly continue. By removing the keystone disturbance of fire, we have essentially impeded or "trammeled" a critical natural processes. But we have the ability to reintroduce a semblance of historical fire effects in wilderness using prescribed fire. Herein lies the paradox: How do we minimize human influences in wilderness areas, while, at the same time, restore those ecosystem dynamics previously altered by humans. Ironically, restoration alternatives will inevitably require human intervention (Bonnicksen and Stone 1985).

Wilderness Whitebark Pine Restoration

Conservation of whitebark pine ecosystems will be nearly impossible without the reintroduction of fire to wilderness areas (Kilgore and Heinselman 1990). Nutcrackers like to cache whitebark pine seeds in openings, especially those created by fire (Tomback and others 1990). Moreover, germinated whitebark pine seeds have the best chance of growing to mature trees in burned areas because these areas are free of competition (McCaughey and Schmidt 1990). As fires are continually suppressed, no burned openings are created and secondary succession, accelerated by rust and beetle mortality, drives the rapid replacement of whitebark pine to subalpine fir and spruce. There is some natural genetic resistance in whitebark pine to the rust with about 1-5 percent of the population showing some mode of resistance. However, without burning, there will be fewer places where seeds from rust-resistant trees can be cached to grow into viable, seed-producing, rust-resistant individuals. Therefore, it appears the most important management action for conserving and maintaining vital whitebark pine ecosystems is to allow fires to burn in wilderness areas and play a more natural role in the ecosystem.

Some wildland fires have been allowed to burn in some wilderness areas since the late 1960's and early 1970's (Parsons and Landres 1998). Many land management agencies developed fire management plans to permit fires started by lightning to burn as long as weather and fuel moistures were within certain limits (that is, prescription). However, these fires, called prescribed natural fires, and more recently termed Wildland Fire for Resource Benefit (WFRB), only burned about 20,000 ha per year from 1972 to 1995 (Parsons and Landres 1998). At this rate, it would take over 2,100 years to burn an area equal to the entire wilderness system. The aftermath of the extensive 1988 fire season halted many wilderness fire programs and forced a national examination of fire policy (Elfring 1989). Only recently has the area burned from WFRB fires started to equal that burned prior to 1988 with over 30,000 ha burned in 1995 alone (Parsons and Landres 1998).

Restoration of whitebark pine ecosystems devastated by rust and fire exclusion may be problematic using treatments other than prescribed natural fires in many wilderness areas. Since most whitebark pine forests are found in remote roadless or wilderness settings with little road access, fire lines used in conventional prescribed fire are costly, damaging, difficult to construct and often in violation of the Wilderness Act of 1964. Silvicultural cuttings would be both difficult to justify due to wilderness regulations and expensive because of poor access, adverse site impacts, and low timber value. Extermination of rust from infected stands using aerial sprays is not a viable or preferred restoration alternative because it is expensive, ineffective and not ecologically sound (Brown 1969). Besides, new, wind-borne infections are always possible in the future, making it more important to have high levels of rust resistance in wilderness populations. Removal of the alternate rust host *Ribes spp.* by mechanical or herbicidal treatments was tried for 30 years but proved a non-viable means of controlling rust (Carlson 1978). Pruning infected branches may delay tree mortality, but ultimately, it is highly probable that future infections will eventually kill the tree (Hoff and Hagle 1990; Hunt 1998). Since pruning and *Ribes* eradication are expensive, they are only feasible in localized, high-use areas, not in large wilderness areas (Dooling 1974; Hunt 1998). Therefore, it seems the best strategy to create the burned openings needed for whitebark pine regeneration in wilderness areas is prescribed fires. Natural breeding for rust resistance can be allowed to proceed as natural regeneration becomes established in burned openings because most seed will be harvested from rust-resistant trees (Hoff and Hagle 1990). Presently, the natural rust resistance breeding process is virtually stifled by fire exclusion.

There are many advantages of WFRB fires. First, ignitions usually occur during the summer, the season when most whitebark pine forests burned historically. Second, a summer ignition can be allowed to burn over many weeks, creating a mosaic of low to high severity fire patterns similar to historical whitebark pine fire burning patterns. Third, more area can be treated more inexpensively with WFRB's than with conventional prescribed fire because fire control structures are minimal and there are usually fewer people managing the fire. Fourth, large WFRB's can create large burned stands where only whitebark pine can colonize because of the long seed dispersal distances of the Clark's nutcracker. It may be easier to implement a stand-replacement fire using WFRB's because crown fires would be difficult to control using conventional prescribed fire techniques. Lastly, WFRB's are more socially acceptable. Their major disadvantage is they can quickly become uncontrollable wildfires because of long burning seasons, highly variable weather, and lack of control structures.

Prescribed natural fires (WFRB) may not be entirely effective in many wilderness whitebark pine forests because when whitebark pine forests are finally dry enough to burn, the adjacent lands in the low elevation forests are in high or extreme fire danger (Brown and others 1994; Kilgore and Briggs 1972). Fire managers will be reluctant to allow lightning fires to burn when only the whitebark pine forests are in prescription and the rest of the landscape is too dry. A possible solution is management-ignited prescribed fires where wilderness fires are ignited by fire crews when conditions are suitable (Brown 1992). Management-ignited prescribed fires have the added advantage of burning extensive areas in a short time, thereby taking advantage of the short-lived burning conditions in high mountain systems (Brown 1991; Keane and Arno 1996). Moreover, they may be the only feasible restoration tool for small wilderness areas where nearly every lightning fire poses potential risk to humans and property (Brown 1991; Husari 1995). Still, most wilderness fire plans do not allow management-ignited prescribed fires at present.

Many have criticized the concept of using management-ignited fires in wilderness areas because it appears unnatural and it has the stigma of human influence. But, extinguishing lightning strikes and actively fighting fires within a wilderness setting is arguably a larger scale trammeling of the wilderness ecosystem (Kilgore and Heinselman 1990). Furthermore, the most deadly factor contributing to whitebark pine decline is the human-introduced blister rust. This disease is rapidly eliminating a keystone species from several wilderness landscapes, and it has accelerated succession to create landscapes with high subalpine fir coverages well outside historical bounds (Keane and others 1994; Keane and Arno 1993; Murray and others 1998). Thus, the impact of this exotic disease, coupled with fire exclusion seems to have created unnatural wilderness landscapes. If naturalness is a wilderness character desired by the public, it seems logical that fire must be restored in wilderness settings to offset the damage done by introduced rust and advancing succession.

Conclusions

Whitebark pine is a keystone species of high mountain ecosystems in most wilderness areas of the northwest United States and western Canada. Wilderness areas are important to conservation of whitebark pine, and conversely, whitebark pine is important to wilderness integrity. Some of whitebark pine forests have recently been declining because of past mountain pine beetle epidemics, current introduced blister rust infections and the continued suppression of fire in wilderness areas. The key to conserving whitebark pine on the wilderness landscape is to allow fire to play its historical role as a recycling process. Fire creates open patches suitable for nutcracker caching and subsequent whitebark pine survival. Without fire, suitable openings for the caching of rust-resistant seeds will not be created, thereby stifling natural rust-resistance breeding processes. An active prescribed fire program for whitebark pine restoration is needed to restore declining ecosystems, but this program cannot rely only on lightning fires. Management-ignited wilderness fires will be needed to ensure adequate burned area because of 1) the large area needing treatment due to extensive rust and beetle epidemics, 2) the large area needed to bring high mountain landscapes back to ecologically suitable conditions after 70 years of fire suppression, and 3) the limited opportunity for prescribed burning from highly variable weather in the high-elevation ecosystems.

Conserving whitebark pine ecosystems may seem a daunting task, but many land management agencies have successfully developed large-scale prescribed fire programs (Parsons and Landres 1996). Some management organizations may want to get started on a smaller scale by implementing prescribed fire restoration projects in small stands to build up expertise and confidence. Not all whitebark pine ecosystems are in need of restoration. Severe sites where whitebark pine is the indicated climax species and sites in the southern parts of its range have not experienced significant rust mortality and adverse effects from fire exclusion, as yet. However, the rust seems to be expanding, and succession is a continual process (Keane and Arno 1994). One thing seems certain: Whitebark pine ecosystems will surely continue to decline if we continue with present management.

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