WHITEBARK PINE (PINUS ALBICAULUS) DECLINE AND RESTORATION IN GLACIER NATIONAL PARK

by

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This thesis, submitted by Kristopher T. Peterson in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota, has been read by the Faculty Advisory Committee under whom the work has been done and is hereby approved.

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This thesis meets the standards for appearance, conforms to the style and format requirements of the Graduate School of the University of North Dakota, and is hereby approved.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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ABSTRACT

In the last century whitebark pine (Pinus albicaulis) has declined precipitously due to white pine blister rust (Cronartium ribicola), mountain pine beetle (Dendroctonus ponderosae), and fire suppression. Historically, fire played an important role in whitebark pine ecology by providing the proper conditions for regeneration and removing competing species. The fire return interval in these areas since effective fire suppression techniques evolved has surpassed the historic intervals that perpetuated whitebark pine. In an effort to appropriately reintroduce fire into whitebark pine communities within Glacier National Park a multivariate GIS analysis was developed which identified habitat conducive to optimal whitebark pine regeneration and growth. Habitat types were grouped into those supporting dominant seral whitebark pine and those that do not. Class signatures of the two groups were derived and applied, yielding their likely geographic distributions in forested subalpine areas (79% accuracy). This GIS coverage is reclassified to display only dominant seral whitebark habitat. Identified potential habitat was prioritized according to contiguous area, probability of occurrence, time since last fire, and relative accessibility.

Approximately 87,500 acres were identified as seral whitebark pine habitat, with the majority of this on the east side of the Park. Areas containing high priority habitat included the St. Mary, Many Glacier, and Belly River subdistricts, and the Muir and Park

Bear Management Zones. Due to the total amounts of habitat, the first three areas were rated as highest priority, respectively.

INTRODUCTION

> Objectively, of course, the various ecosystems that sustain life on the planet proceed independently of human agency, just as they operated before the hectic ascendancy of Homo sapiens. But it is also true that it is difficult to think of a single such natural system that has not, for better or worse, been substantially modified by human culture. Nor is this simply the work of the industrial centuries. It has been happening since the days of ancient Mesopotamia. It is coeval with writing, with the entirety of our social existence. And it is this irreversibly modified world, from the polar caps to the equatorial forests, that is all the nature we have….Even the landscapes that we suppose to be most free of our culture may turn out, on closer inspection, to be its product.
>
> - Simon Schama, Landscape and Memory

We have evolved as humans to become great manipulators of the environment in which we reside. It was once a popular belief (and remains among many) that nature should be left alone if there is any hope of preservation. This concept remains valid in many respects. However, our influence is so extensive that there is no possibility of its removal. Whether a direct manipulative approach or a hands-off approach the influence exists. As Schama suggested, many of the regions of earth we view as sheltered from human influence are indeed the consequence of our activities. Our influence is not bound to our immediate physical environment. Human effects on the earth's atmosphere, oceans, and polar regions are all too well known. A less known area of influence is that over the subalpine regions of the earth's mountain ranges. The decimation of whitebark pine (Pinus albicaulis), a timberline tree species, is an example of our effects on an environment to which we are not directly linked. The decline of whitebark pine is a consequence of both direct and indirect environmental manipulation – introduced disease, fire suppression and subsequent deleterious biotic responses, such as native insect outbreaks.

Whitebark pine is a subalpine stone pine (five-needle pine) in the Cascade, Sierra Nevada, and northern Rocky mountain ranges, including Glacier National Park (fig. 1). More than 17 wildlife species, including black bears (Ursus americana), Clark's nutcrackers (Nucifraga columbiana), red squirrels (Tamiasciurus hudsonicus), and grizzly bears (Ursus arctos horribilis), feed on the large pine seeds produced by these trees (Kendall and Arno 1990; Appendix A). The seeds are especially significant in grizzly bear ecology. High in fats and highly preferred, the seeds are an important food for grizzly bears who feed on pine seeds found in squirrel middens. The seeds are such a critical food for grizzly bears in the Greater Yellowstone Ecosystem that reproduction and survival are positively correlated with whitebark pine cone crop (Mattson 1987; Mattson et al. 1992). Moreover, the location

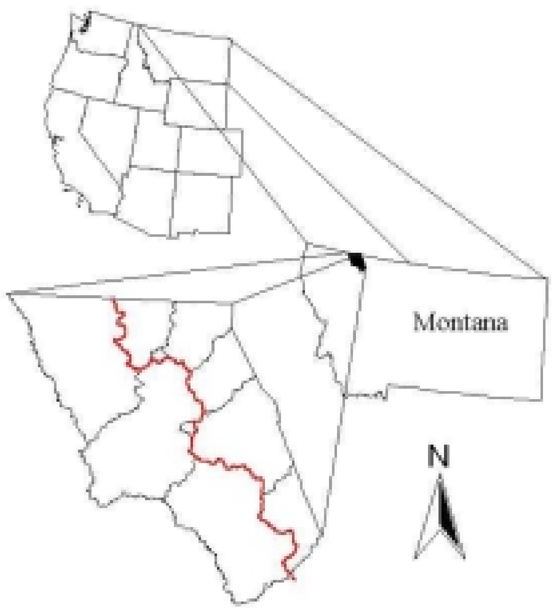

Figure 1. Location of Glacier National Park in the western U.S. Management subdistricts are outlined within the Park boundary.

of most whitebark pine stands in remote subalpine environments means that bears feeding on whitebark pine seeds are removed from the majority of human activity, reducing the potential for bear-human conflict. In addition to its importance to wildlife, whitebark pine provide edaphic and hydrological benefits. Their spreading crowns and ability to grow on windy ridges result in snow accumulation and retention. These attributes provide for higher, deeper snowpack, delayed meltoff, and soil stability.

Despite the importance of this tree species, the number of whitebark pine is declining precipitously in Glacier National Park in the last 60 years; currently 30-50% of the trees are dead in many areas (Kendall and Schirokauer 1997). Of the remaining live trees, few are healthy and producing seed bearing cones as white pine blister rust (Cronartium ribicola) tends to kill the tops of trees first (cones are produced on the top portion of the tree's crown). Fire suppression and resultant mountain pine beetle (Dendroctonus ponderosae) epidemics are also factors contributing to the decline (Morgan and Bunting 1989; Murray 1994; Tomback 1995).

Several studies have looked at whitebark pine regeneration post-fire. The 1988 fires of Yellowstone National Park (YNP) provided an opportunity to explore post-fire regeneration of whitebark pine habitats. Preliminary results of Tomback (1995) were inconclusive. However, the results suggest that whitebark pine regeneration was greater and dominant at dry sites that experienced more severe fire. Another study looked at regeneration after the Sundance Burn in Northern Idaho (Tomback et. al., 1995). Comparisons were made to two other burns in western Montana, the Sleeping Child Burn in the Sapphire Range and the Saddle Mountain Burn in the Bitterroot Mountains. It was found that regeneration was significantly reduced in the area of the Sundance Burn due to deleterious effects of blister rust on the available seed source. Tomback et al recommended that prescribed burns should be accompanied by the planting of rust-resistant seedlings post-fire.

Differences are noted between these areas and the Greater Glacier Ecosystem. For example, the incidence of blister rust is greater in GNP than in YNP (Kendall, unpublished data). The greater selective pressure presumably produces a greater proportion of blister rust resistant seeds. However, the number of cones, and consequently seeds, produced is much less. In this scenario, Clark's Nutcracker may consume a much larger proportion of whitebark pine seeds, diminishing the available seed source for regeneration. William's (1999) seed collection campaign serves as a safeguard against the potential over-harvest of seeds by Clark's Nutcracker.

Keane et al (1996) produced a detailed fire simulation model that followed forest succession after specified fire events or other disturbances. The model, specific to coniferous forests of the Northern Rocky Mountains, was applied to a study area for which forest structure data had been gathered – the Monture Simulation Study Area in the southwest portion of the Bob Marshall Wilderness Complex in northwestern Montana. The results of this application are replicated in figure 2 (a-d), adapted from Keane et al 1996. As these figures demonstrate, the model predicts the loss of whitebark communities to subalpine fire communities in all but the historical (pre-settlement) fire regime.

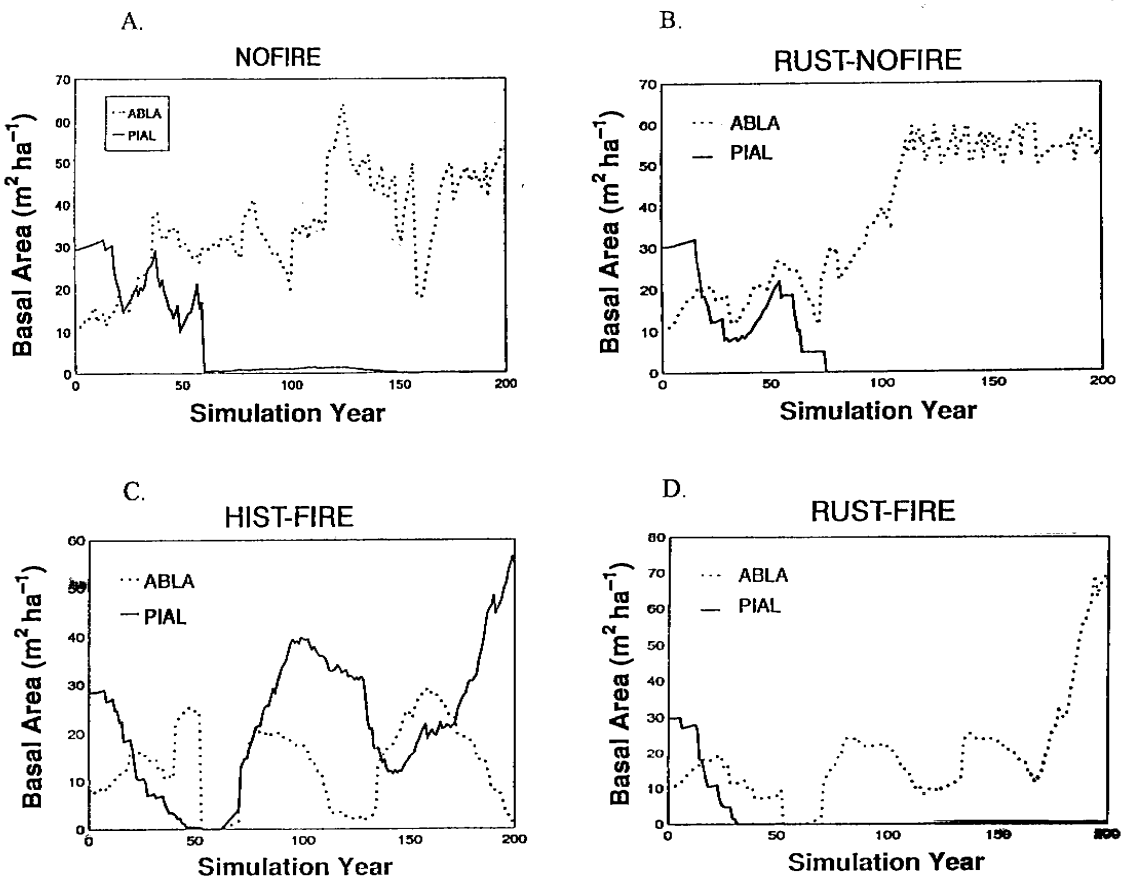

Figure 2. FIRE-BGC predicted basal areas over a 200 year simulation for four scenarios: A) in absence of fire and blister rust, B) in absence of fire with blister rust present, C) historical fire regime only, and D) blister rust and fire present. (Adapted from Keane et al., 1996).

Murray (1996) came to similar conclusions in his forest successional modelling for the West Big Hole area straddling the Montana-Idaho border. A dominance shift to late seral species was determined for the last 50 years. This shift was predicted to continue during the next 200 years if fire as a major disturbance was not reintroduced to this ecosystem.

Based on these findings and others, many have recommended the reintroduction of fire to whitebark pine habitat in order to initiate the restoration process (Murray 1996, Kendall and Schirokauer 1997, Keane et al 1996, Keane and Arno 1996a.) This paper response to these findings and recommendations. Below is a summary of the problems associated with the decline of whitebark pine and a detailed first step to a restoration effort, specific to Glacier National Park. Seral whitebark pine habitat is spatially identified and subsequently prioritized in Glacier National Park fir prescribed natural fire based on ecological and management cosiderations. The fire return interval in this habitat since fire management policy was loosened in 1978 is evaluated here as well.

STUDY AREA

Glacier National Park is located in the northwest part of Montana and lies between 48^{o} 13' and 49^{o} north latitude and 114^{o} 30' and 113^{o} 10' west longitude and encompasses 1,013,572 acres (fig. 3). Of this area approximately 646,500 acres are above 5000 feet, of which 330,000 acres are coniferous forest. The park straddles the continental divide providing two fairly diverse environments. In addition, the park hosts parts of three first order drainages, which include the Hudson Bay, Missouri and Columbia Basin drainages, contributing further to diversity. The Park is bordered almost exclusively by federal and state lands (fig. 2). Within the Park ten Management subdistricts are designated. These subdistricts are further broken down according to Bear Management Zones (BMZ).

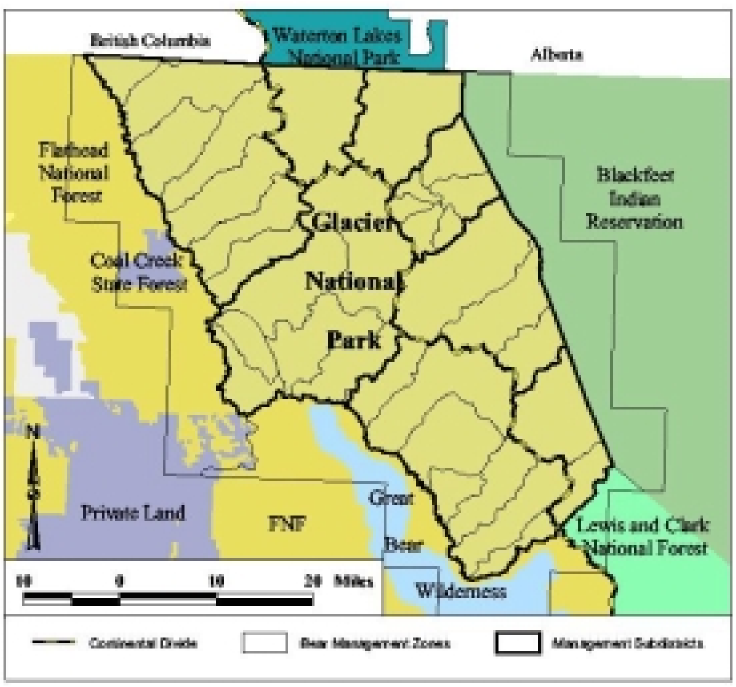

Figure 3. Management subdistricts, and Bear Management Zones within Glacier National Park; Ownership outside of the Park.

The primary objective of the National Park system, including Glacier National Park is to, "preserve and protect natural and cultural resources unimpaired for future generations" (NPS 1998). As described above, whitebark pine has declined significantly in the last 60 years, predominantly due to human influences (see History of Impacts). In order to reconcile this problem, action must be taken to reestablish whitebark pine to a semblance of its original extent, condition, and ecological role.

More than 370 plant species are found above 5000 feet (1524 m) elevation. The more common of these species are listed in Appendix B. Dominant tree species include Engelmann spruce (Picea engelmannii), subalpine fir (Abies lasiocarpa), subalpine larch (Larix lyallii), and whitebark pine (Pinus albicaulis). Engelmann spruce begins to decline around 5900 feet (1800 m). Although the latter three trees have historically dominated forest communities above this elevation, subalpine fir is becoming increasingly more dominant as a result of fire suppression. Also common at these higher elevations are wet and dry meadows, shrub communities (usually in avalanche chutes), and rocky communities. There are no federally listed threatened or endangered plant species in the park, however, there are a number of state listed threatened, sensitive, or rare species.

Conversely, there are five federally protected animal species in the Park. These species include the bald eagle (Haliaèetus leucocèphalus), gray wolf (Canis lupus), grizzly bear (Ursus arctos horribilis), peregrine falcon (Fàlco peregrìnus), and bull trout (Salvelinus confluentus). Of these species grizzly bears spend the most substantial time in the higher elevation areas, including whitebark pine communities. Other wildlife species directly related to whitebark pine habitat are listed in Appendix B, along with their tolerances to fire.

Much of the area above 5000 feet (1524 m), approximately 297,000 acres (120,000 hectares), is exposed rock. Siltite, arenite, argillite, dolomite, dolarenite, quartzite, limestone, mudstone, sandstone, siltstone, alluvium, colluvium, till, landslide deposits, and lava are characteristic of the geology of this area. Geologic formations include the Blackleaf, Kootenai, Kishenehn, Altyn, Appekunny, Prichard, Empire, Grinnell, Helena, McNamara, Mount Shields, Shepard, Snowslip, and Waterton formations (compiled and mapped by J. W. Whipple 1992). Based on geologic and hydrologic characteristics of the soil Barry Dutton (1997) identified the following four soil types: alluvial soils; wet soils; glacial, landslide and mixed soils; and bedrock soils. Soils have been mapped only for the east side of GNP and the Lake McDonald drainage. (Please see Dutton 1997 for more details).

HISTORY OF IMPACTS

White Pine Blister Rust

Of the approximate 23 diseases and harmful insects that parasitize whitebark pine (Hagle et al. 1987, Hoff and Hagle 1990; see Appendix C), white pine blister rust (Cronartium ribicola) is unquestionably the most damaging (Hoff and Hagle 1990). White pine blister rust is an exotic fungus introduced on the West Coast of North America c.1910. Infection on the East Coast of North America preceded the West Coast infection. A close watch for the fungus ensued earlier in the West in an attempt to stem the potential threat before it became established. Despite the effort, the fungus arrived on a shipment of eastern white pine (Pinus strobus) from Pierre Sebire and Son, Ussy, France. From Point Grey near Vancouver, BC, where it was discovered by A. T. Davidson in 1921, the fungus spread northeast and southeast, reaching the range of whitebark pine quickly thereafter. The rust rapidly decimated its five-needle pine hosts in Olympic and Mt. Rainier National Parks before management action was implemented. Within 13 years blister rust had spread throughout the entire range of western white pine (Pinus monticola; Hoff and Hagle1990), the most valuable timber species at the time. A Blister Rust Control (BRC) office was promptly established in the West with the responsibility of delaying spread, controlling local infections, and conducting research on the fungus in the West (Benedict 1981). It is important to note that the incentive to control this disease stemmed from the potential economic loss associated with the threat to western white pine. Beginning in 1923, the Forest Service initiated Ribes spp. (alternate host of white pine blister rust) eradication programs. The Park Service soon followed in the early 1930's. During this decade the BRC took advantage of programs such as the Civilian Conservation Corps (CCC), the Public Works Administration (PWA), and the National Industrial Recovery Act (NIRA) employing thousands of men and securing necessary funding for its blister rust programs.

However, World War II pulled most of these men away from the BRC program. Realizing the desperation of the western office, the Washington, D. C. BRC office promptly sent war prisoners, Mexican nationals, high school boys, and delinquent youths as replacements (Benedict 1981). The eradication program quickly renewed after the war and continued for several decades. Before these programs ended in the early 1970's, over 15 million Ribes spp. were manually removed from Glacier, Grand Teton, and Yellowstone National Parks, with 4.6 million from Glacier National Park alone (Hoff 1990). In addition to the manual removal of these plants, chemical means were employed. This eradication method involved approximately 536,000 gallons of 2-4-5T herbicide (Kendall 1998) and invariably affected surrounding vegetation. Experiments were also performed with antibiotic fungicides. However, after the aerial application of these chemicals to over half a million acres the fungicides proved ineffective. Due to the great expense of these programs, funding soon ended and brought the eradication programs to an end in 1967 in the Northern Rocky Mountains.

Genetics resistance projects, perhaps the most viable of programs, began in the 1940's when it was observed that not all trees appeared to be susceptible to blister rust damage. Ray Hoff, one of the pioneering researchers in this field, originally found whitebark pine to be the most susceptible five-needle pine with less than one in 10,000 trees having resistance (Hoff 1998). However, due to the high selective pressure of blister rust, this percentage is increasing (Hoff 1998). In response to this trend, Tara Williams, Ecologist for Glacier NP, began a seed collection campaign in the Park during 1997. The collected seeds were sent to the genetics lab at the University of Idaho in Boise where they await testing for genetic resistance. The plan is that resistant stock will be propagated and replanted in appropriate areas where fire has been reintroduced. This strategy is probably the best alternative given the apparent permanence of blister rust in these ecosystems.

Fire Suppression

In Barrett's (1983, 1988) analyses of pre-settlement fire patterns on the western side of the continental divide, Native American impact is not considered. Two archeological studies performed in the early 1990's, however, may shed light on this issue. The number of pre-settlement sites suggest extensive indigenous use of the area (GIS data from studies of Barney Reeves and Midwest Archeology Center). Although indigenous peoples are known to use fire for a multitude of purposes (Anderton, personal communication), these studies do not provide evidence for or against this. Barrett's analyses of the eastside (1993, 1997), however, does discuss Native American influence. He suggests that the fire history data point toward heavy use of fire by the Blackfeet, by pointing out the discrepancy between the low frequency of lightening and the low fire return intervals.

At the beginning of this century the mentality of forest managers in the West concerning fire was similar to that of blister rust control – all out warfare. Two main motivators were involved in the movement toward suppression. First, there was a desire to have a controlled environment in which settlement could occur. Second, fire was viewed as counterproductive to the concept of preservation – fire destroyed what the public wanted preserved. The intense fire seasons of 1910, 1926, and 1929 reinforced this sentiment and the fear associated with a force that was not to be easily controlled.

Pyne (1982) suggests that, "[the] infusion of Americans into the region had a mixed result." Barrett (1983) also noted an increase in the frequency large fires during what is defined as the Settlement Period by Singer (1975). Several explanations for this increase have been suggested, including careless settlers, railroad construction and operation, and drought coupled with lightning strikes (Ayers 1900; Barrett 1983). In Glacier National Park, human caused fires as identified by Key (1984) and Barrett (1988, 1993) indicate an enormous influence during white settlement (fig. 3). Although drought may have contributed to the magnitude of these fires, the ignition sources were overwhelmingly human. This is especially true on the east side of the park where few lightening strikes occur (Barrett 1993). Key (1984) explains that of the 47,613 acres burned within the North Fork Flathead River drainage between 1910 and 1929, nearly half (22,689 acres) were a result of human ignited fires.

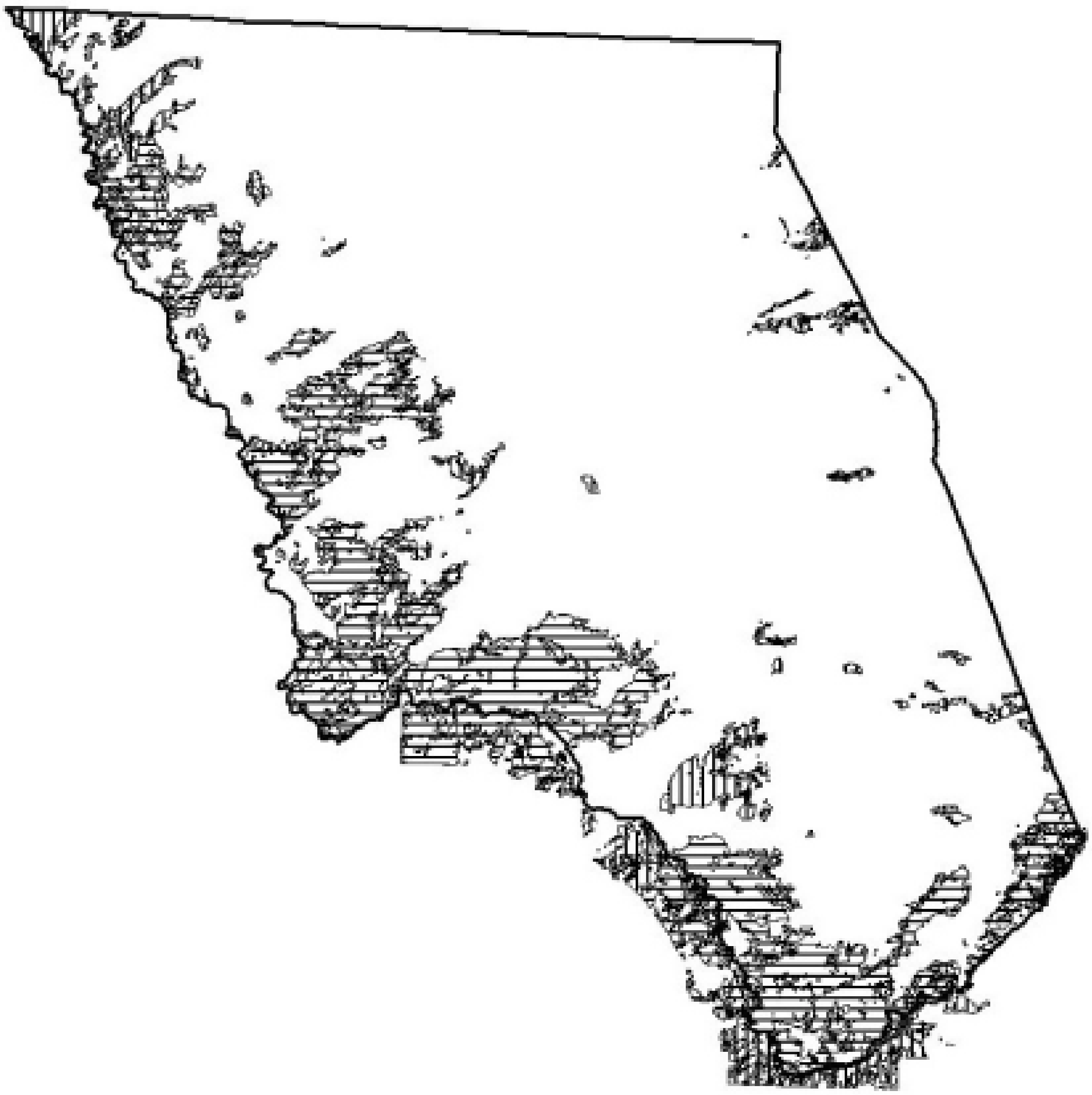

Figure 4. Approximate extent of human caused fires during the Settlement Period (1900 – 1929). Human ignited fires shown by horizontal lines; lightening or other ignitions shown by vertical lines.

Although settlers were responsible for the early increase in fires, they quickly reversed their impact. Efficient fire suppression began after the 1929 fire season with the development of more effective fire management technology and strong political and financial support (Benson 1993; Pyne 1982). The amount of area burned between

1930 and the early 1990's is less than eight percent of the amount burned during the first 30 years of this century (fig. 4).

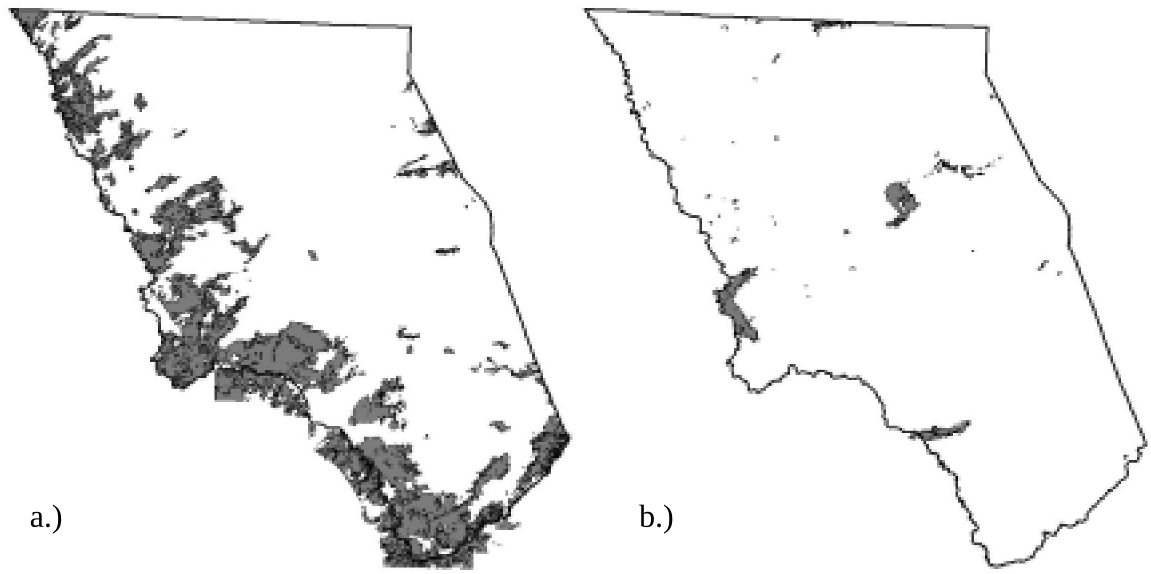

Figure 5. Comparison of fires during a) the Settlement Period (1900 – 1929), and b) the Post-Settlement Period (1930 – 1994).

It was known even in the mid-thirties that fire played a natural role in providing valuable wildlife habitat. However, insufficient data had been collected to support this positive interpretation of fire in the ecosystem and the aesthetic loss outweighed these benefits (Benson 1993). Prevailing thought during this time asserted that climax successional forest communities were the most stable and thus desired. Therefore, it was ecologically, as well as, politically justified to exclude fire from the environment. Adolph Murie, Assistant Wildlife Supervisor for the National Park Service, was not convinced of this (Benson 1993). Murie adamantly opposed fire suppression, but was unsupported by his colleagues. The question of fire's ecological importance was not significantly re-addressed until 1963 when the Advisory Board on Wildlife Management submitted a report that evaluated the Park Service's resource management policy. This report quickly became influential in terms of fire management and policy subsequently evolved to be more accepting of the role fire plays in ecosystem processes (Benson 1993; Pyne 1982). However, it was not until 1978 that Glacier National Park changed its fire management policy to incorporate this new philosophy. (This date is used in the later analysis of the fire return interval of seral whitebark pine communities.) Moreover, only 5,000 forested acres (of the Park's 1,013,595 acres) fell under zones allowing prescribed fire (Benson 1993). It is arguable that nearly complete fire suppression continued until the last few years when a few small management ignited fires took place. The fires during the early fall of 1998 were perhaps the largest fires within the park in almost 70 years.

As the first step in a reevaluation of fire management policies, studies were conducted by Barrett from 1982 to 1996. These studies culminated in several reports (Barrett, 1983, 1986, 1988, 1993, 1997) and a map (produced by Richard Menicke and Carl Key) of the fire history of Glacier NP. In a summation of his first study of the North Fork region, Barrett (1983: 40) states, "...the North Fork forests are approaching or have just exceeded the upper limits of their past range of fire intervals," and later continues (47),"…park managers still have the opportunity to reintroduce fire into the [region] before substantial ecological impacts occur." In his later fire history reports that cover other areas of the Park, Barrett continued to emphasize the need to allow fire to play its historic ecological role, while stating that stands have not yet reached or surpassed historic fire intervals.

Historically, fire played an integral role in providing suitable regeneration habitat for whitebark pine by removing competing species, such as subalpine fir (Abies lasiocarpa) and Engelmann spruce (Picea engelmannii), and providing necessary conditions for regeneration (Arno 1986, Morgan and Bunting 1989). Arno (1986) suggested a fire return interval in the Northern Rockies of 100 to 150 years for these communities. In addition to being slightly more resistant to creeping ground fire than are other forest trees, whitebark pine is also adapted to harsh climates and can thrive in the exposed and dry post-fire conditions. Furthermore, the open areas produced by fires attract Clark's nutcrackers, which prefer these areas to cache their harvested whitebark pine seeds. This transport of whitebark pine seeds into large burns gives whitebark pine a competitive advantage over wind-dispersed seed species. The absence of fire in whitebark pine communities allows late seral species such as subalpine fir and Englemann spruce to invade and out-compete the early seral whitebark pine communities.

Barrett's studies either did not assess (on the west side), or did not adequately assess (on the east side), the fire history of vegetation communities above 5500 feet. A more recent study of whitebark pine communities in Glacier National Park conducted between 1995 and 1997 recommends the reintroduction of fire (Kendall and Schirokauer, 1997). Moreover, recently documented fire history not recorded in Barrett's studies suggests that seral whitebark pine communities have surpassed their historic fire return intervals (see RESULTS). Other data indicate that successional status of whitebark communities are skewed toward the latter stages in Glacier National Park (Kendall et al.

[unpublished data]) and in other areas of the Northern Rockies (Morgan and Bunting 1989). The lack of fire in these communities has not directly contributed to the death of these trees. However, fire suppression has not allowed for adequate regeneration and, if fire is not reintroduced to these areas, necessary regeneration will not occur. Barrett (1993) was unsure, "whether fire suppression has measurably influenced ecosystem functioning to date." It is apparent, however, that whitebark pine regeneration has been negatively influenced.

Mountain pine beetle

Mountain pine beetle (Dendroctonus ponderosae, MPB) at endemic levels tend to prefer lodgepole pine (Pinus contorta) as its host, however, at epidemic proportions these beetles are less selective (Bartos and Gibson 1990) and therefore are more likely to attack whitebark pine communities. Most beetle-killed whitebark pine stands are a result of the stands close proximity to lodgepole pine stands. However, whitebark pine stands can be infested in the absence of nearby lodgepole pine stands (Bartos and Gibson 1990). MPB prefer larger trees that have an inner bark layer capable of supporting their larvae. The larger trees are usually the most productive in terms of cone production in whitebark pine. Additionally, resistance to MPB generally decreases with age in pines. Due to fire suppression much of the forests in the West continued to age and tree diameters increased. The senescent stands, particularly of lodgepole pine, invited MPB epidemics that eventually spilled over into whitebark pine habitat (Arno 1986). Many claim that these beetle epidemics killed several whitebark pine communities that historically would not have been as affected. Several of the larger beetle infestations within Glacier NP are identified in Table 1.

Barrett (1983) suggested that the extensive under-burns during the early part of this century, which cleared the underbrush from many of the lodgepole pine stands, allowed these trees to grow and subsequently attract mountain pine beetle more quickly. He later dismisses this argument and states that the epidemics are part of the lodgepole

Table 1. History of mountain pine beetle epidemics in Glacier National Park. LP = Lodgepole pine, WP = Western White Pine, WBP = Whitebark Pine.

Year	Host Species	Acreage
Early 1960's[1]	LP, WP	100's
1970's[1]	LP, WP	Unspecified
1980[2]	LP	292,000
	WBP	15,000

[1]Gibson and Oakes 1989
[2]Bartos and Gibson 1990

regeneration cycle. Due to the absence of literature and research concerning pre-settlement MPB epidemics a comparison of pre-settlement to post-settlement MPB pestilence is not possible. Therefore, only an educated guess can be offered based on the ecology of MPB and forest dynamics of the past century that MPB have had a negative impact on whitebark pine communities.

METHODS

Identification of Seral Whitebark Pine Habitat

Habitat conducive to optimal whitebark pine regeneration is identified here. The produced GIS layer is useful in prioritizing whitebark pine habitat where restoration efforts may be concentrated. Potential dominant, seral whitebark pine habitat (hereafter referred to as potential habitat) is identified through a multivariate analysis of several physiographic GIS layers, using ECODATA plots performed by Kendall et al (1995-1997) as sample points. This work was accomplished in GRID ARC/INFO.

The 357 sample points used for the analysis were habitat type (Pfister et al 1977) point data from the aforementioned ECODATA vegetation plots, which were contained in an ARC/INFO point coverage. Forty-two habitat types were reclassified into two groups. The first group was of those habitat types supporting dominant, seral whitebark pine (habitat types Abies lasiocarpa-Pinus albicaulis/Vaccinium scoparium (820) and Abies lasiocarpa/Luzula hitchcockii-Vaccinium scoparium phase (831)); the second group comprised all other habitat types. This habitat group coverage was divided in two, using the continental divide as the separation, and converted to raster format. Canonical discriminant analysis suggested better separation between groups when the data was divided between the east and west sides of the continental divide. Eighty percent of the samples were randomly chosen from each of the two point coverages. These samples served as the training data in the following steps. The remaining 20 percent were later used for accuracy assessment of the classified vegetation layer.

There are three main environmental/landscape factors that effect the spatial distribution of habitat types. These factors include topography, geology/soils, and climate (Pfister et al 1977). Presently available and complete (park-wide) GIS layers allow for analysis for only topography. These layers include slope, aspect, and a Digital Elevation Model (DEM). Two other GIS layers were derived that increased the accuracy of the analysis, water flow accumulation (for the west side) and distance from the continental divide (for the east side).

In order to fit the parameters of the classification, the set of values within each data layer needed to be linear and have equal ranges in relation to each other. For all layers except the aspect layer this required only a multiplicative reclassification. However, the aspect layer required first a geometric conversion to produce linear values. A Cosine conversion satisfied this requirement and provided values that reflected sun exposure. The converted aspect layer was then reclassified to provide values with the same range as the other data layers. Two stacks of these grids were created (fig. 6), one for each side of the divide. Sample files were derived that contained stack data for each point in the sample grid. For example, point one is a seral whitebark pine habitat type at 6500 feet elevation, 30 percent slope, etc. Class signatures were derived from these files for each of the two habitat type groups. These class signatures were applied to the stacks from which they were derived using the maximum likelihood classifier in GRID ARC/INFO. This application yielded delineations of seral whitebark pine habitat and all other habitat. A mask was then applied that revealed only coniferous forest above 5000 feet (1524 m). This step eliminated barren areas that were misclassified as forest. The GIS layers for each side of the continental divide were then merged to form a single layer. The remaining 20 percent of the original sample points were used for an accuracy assessment. These points were overlaid onto the classified vegetation grid and analyzed.

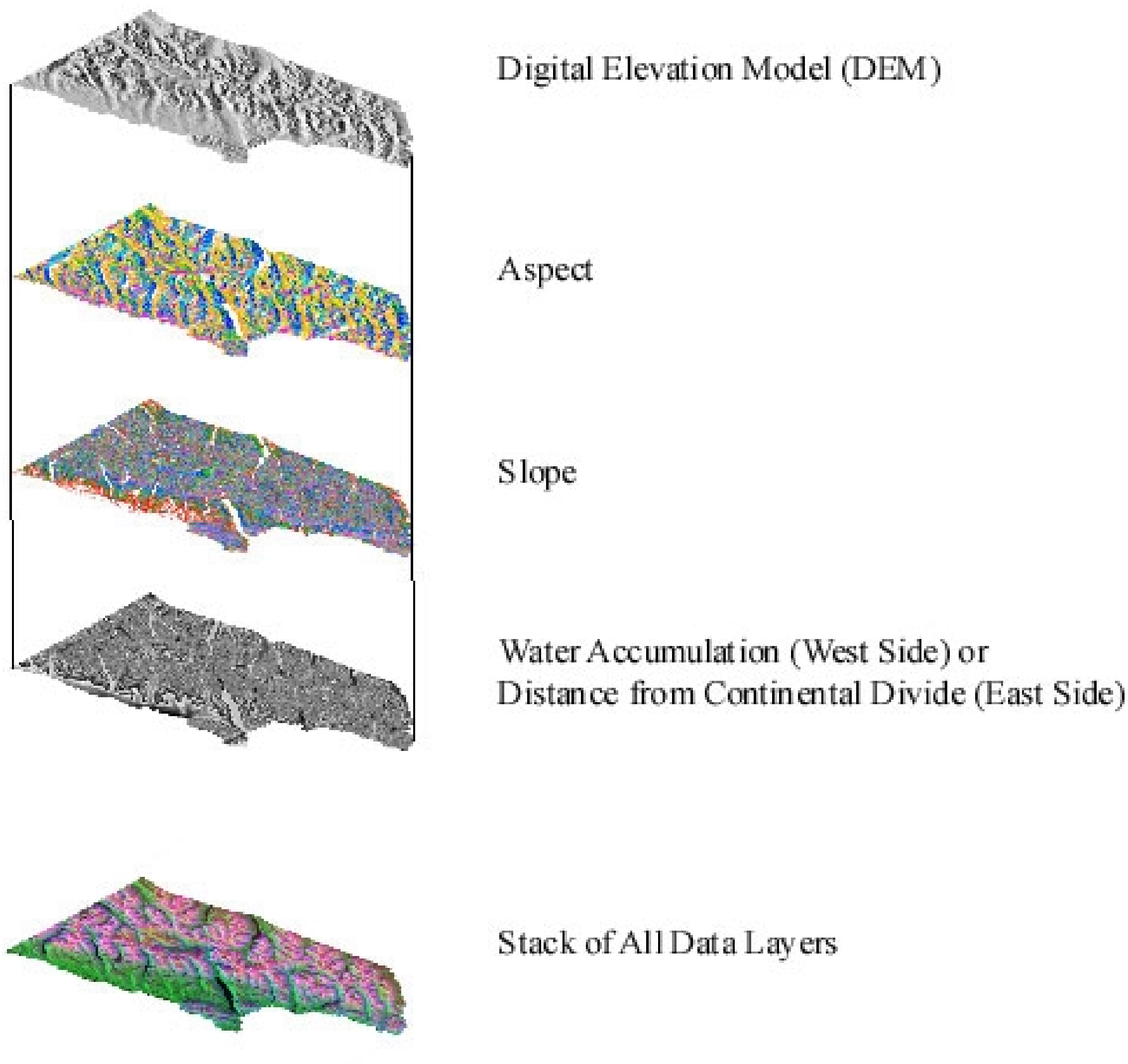

Figure 6. Production of grid stack from multiple data layers.

The identified potential habitat also allowed for an analysis of recent fire return intervals for these forest communities. The potential habitat GIS grid was overlaid with a GIS grid containing all major fires (greater than 20 acres) between 1978 and 1998. Overlap of the two grids was measured and analyzed temporally for area burned and recent fire return intervals.

Prioritization of Potential Whitebark Pine Habitat

Before prioritization, potential habitat was grouped into stand aggregates. These stand aggregates are subjectively defined based on a potential burn area and are named based on a close physical feature, such as a mountain peak or drainage. The potential habitat is then prioritized for prescribed fire based on the following factors – total area, probability of occurrence, fire history, and accessibility. Potential habitat is prioritized at two scales – management subdistrict (on the east side), and Bear Management Zones (on west side). The different designations are used for the east and west sides in order to make the prioritizations spatially manageable.

Stand aggregates with greater total area within a potential burn area receive higher prioritization. A WSAL vegetation and land cover layer (created by Redmond et al 1996) is used to predict the probability of occurrence. Percentage of overlap between potential habitat and those covertypes that support whitebark pine is determined for each stand aggregate. Stand aggregates with higher probability of occurrence are prioritized higher. The stand age maps resulting from Barrett's fire history studies (1983, 1986, 1988, 1993, and 1997) are overlaid over the potential whitebark pine habitat layer. Potential habitat of greater stand age (reflecting a greater time since last fire) is prioritized higher.

Accessibility is determined by a cost-distance analysis that accounts for distance from trails and the slope of the terrain. It is important to note that vegetation is not considered in this model; the model only projects relative accessibility. This prioritization is used for several reasons. First, sites more accessible than others provide easier transport of equipment and personnel during and in preparation for a prescribed natural fire. Second, potential habitat chosen for later planting of whitebark pine seedlings must be reasonably accessible for vegetation crews to get in to plant. Finally, where public outreach is possible, potential habitat must be extremely accessible or within site of a well used area.

RESULTS

Spatial accuracy for the identified potential habitat is 83 percent for the west side and 76 percent for the east side, with a combined accuracy of 79 percent overall (Table 2). Approximately 87,500 acres were classified as seral whitebark pine habitat within the

Table 2. Results of Accuracy Assessment.

Actual Habitat Type Group	Predicted Habitat Type Group	Correct	Number of Plots (East, West)	Total Number of Plots	Percent (East, West)	Total Percent
Seral WB[1]	Seral WB	Yes	2, 3	5	8, 17	12
Other[2]	Other	Yes	17, 12	29	68, 67	67
Seral WB	Other	No	0, 1	1	0, 6	2
Other	Seral WB	No	6, 2	8	24, 11	19
Total Correct Prediction		Yes	19, 15	34	76, 83	79
Total Incorrect Prediction		No	6, 3	9	24, 17	21

[1] Seral whitebark pine habitat types
[2] All other habitat types

Park (Table 3). The east side contains the majority of this habitat, more than 70,000 acres. However, the accuracy assessment suggests that the classification over-predicted the extent of potential habitat on the east side (Table 2).

Given this area and Arno's (1986) calculated fire return interval for seral whitebark pine habitat in the Northern Rocky Mountains (100-150 years), between 580 and 875 acres historically burned within the park each year. Between the years 1978 and 1998 the actual fire return interval was 720 years or 121 acres burned per year.

Table 3. Areas and densities of potential habitat according to Bear Management Zones and subdistricts.

Subdistrict (and BMZs)	ACRES	Acres of Potential Seral WB Habitat	Density of Potential Seral WB Habitat	
St. Mary Subdistrict	**128,368.209**	**24,999.815**	**0.195**	
Saint Mary	70,307.515	13,138.602		0.187
Red Eagle	37,014.455	7,681.053		0.208
Cut Bank	21,046.239	4,180.160		0.199
Many Glacier Subdistrict	**60,423.951**	**12,120.704**	**0.201**	
Many Glacier	14,535.839	5,280.989		0.363
Grinnell	9,573.655	980.446		0.102
Iceberg-Ptarmigan	5,262.723	389.459		0.074
Swiftcurrent	5,524.835	334.172		0.060
Cracker	5,912.066	407.739		0.069
Gable	19,614.833	4,727.899		0.241
Belly River Subdistrict	**64,311.267**	**13,663.157**	**0.212**	
Belly River	64,311.267	13,663.157		0.212
Goat Haunt (and Kootenai) Subdistricts	**60,558.315**	**10,190.130**	**0.168**	
Waterton Drainage	60,558.315	10,190.130		0.168
Two Medicine Subdistrict	**59,976.513**	**9,282.359**	**0.155**	
Two Medicine	44,360.296	8,615.130		0.194
Lubec	15,616.217	667.229		0.043
Middle Fork Subdistrict	**202,209.194**	**6,711.308**	**0.033**	
Harrison	20,827.532	771.561		0.037
Nyack	57,259.744	1,675.765		0.029
Coal	39,547.534	963.281		0.024
Park	26,753.755	742.580		0.028
Ole	32,919.429	1,852.771		0.056
Muir	12,874.557	489.331		0.038
Bear	12,026.643	216.019		0.018
McDonald (and Hidden) Subdistricts	**213,983.792**	**6,102.484**	**0.029**	
Camas	46,266.347	533.694		0.012
Upper McDonald	70,480.063	5,155.702		0.073
McDonald Lake	36,554.600	183.917		0.005
Huckleberry	14,639.437	18.057		0.001
Apgar-Lower McDonald	18,651.069	5.350		0.000
Lincoln	27,392.276	205.764		0.008
North Fork Subdistrict	**220,669.145**	**4,499.619**	**0.020**	
Kishenehn	14,248.806	111.465		0.008
Kintla	42,099.117	1,470.669		0.035
Bowman	36,585.389	857.835		0.023
Akokala	33,040.133	407.962		0.012
Quartz	40,585.967	762.644		0.019
Logging	30,407.751	705.573		0.023
Anaconda	23,701.982	183.471		0.008
Total	**1,010,500.386**	**87,569.576**	**0.087**	

Approximately 2,550 acres of potential habitat have burned since 1978. The majority of this area (96 percent) burned in a single year – 1998.

East Side Prioritization

Due to its leeward location to the Northern Rocky Mountains the east side hosts a drier climate. This attribute gives the east side greater potential for escaping or uncontrollable fires. The pre-settlement fire regime comprised fairly frequent stand replacement fires. Due to the differences between this and the frequency of lightening ignition, it has been suggested that Native Americans had a substantial influence on the fire return interval (Barrett 1993, 1997). Winds are most frequent from the west compounding the problem of fire control. Moreover, because of the lack of natural barriers between the park and the grasslands on the Blackfeet Indian Reservation, much more care must be taken to avoid trespass of fires onto this land.

Goat Haunt and Kootenai Subdistricts

The Goat Haunt Subdistrict (fig. 7) hosts the fourth largest amount of potential habitat per subdistrict and the third largest per BMZ (Waterton Drainage; Table 3). However, it is the most inaccessible part of the park. The two largest stand aggregates are found in the Waterton River and Valentine Creek drainages. Another large concentration of potential habitat lies in the northern portion of the subdistrict in the Shaheeya Lake drainage. Although the smallest, the latter drainage has the best probability of occurrence (table 4). All other priority characteristics are the same. None of these stand aggregates show any evidence of recent fire activity (Barrett 1997).

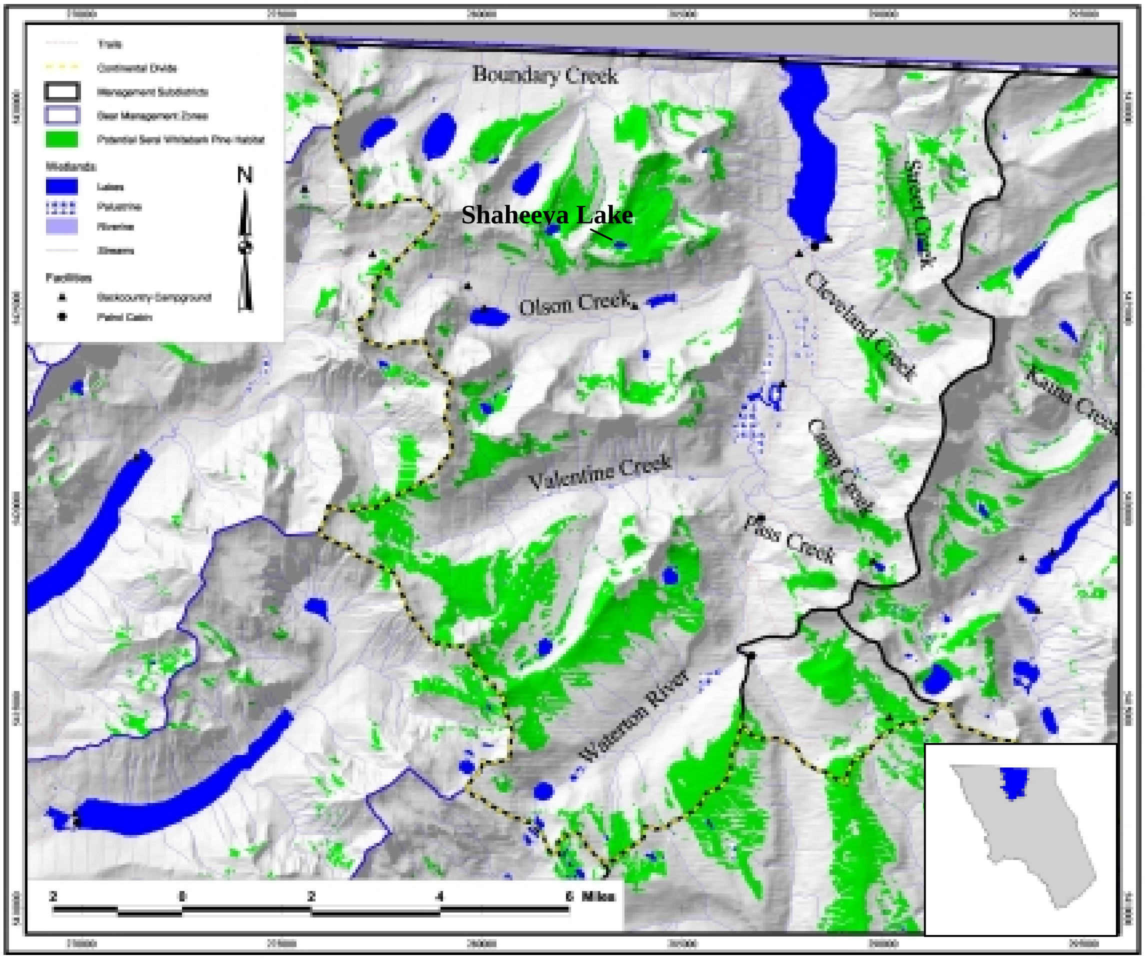

Figure 7. Hillshade image of Goat Haunt and Kootenai subdistricts showing potential seral whitebark habitat.

Although the Waterton River and Valentine Creek drainages contain similar amounts of potential habitat (about 2000 acres), the recent fire activity near the former drainage (on and around Flattop Mountain) lowers slightly the priority of this area. The Shaheeya Lake drainage is prioritized last due to its small size and apparent snow and water retention capabilities, suggested on aerial photographs. The latter attribute favors earlier succession of subalpine fir and Englemann spruce, and favors subalpine larch on the north facing slopes as suggested by ECODATA collected in the area.

Table 4. Priority statistics and information concerning stand aggregations within the Goat Haunt and Kootenai subdistricts.

Stand Aggregate	Approx. Acreage	Relative Probability	Fire History	Relative Accessibility	Subdistrict Priority	Cooperation Needed
Valentine Creek	2200	67%	N[1](51%); no forest(43%)	Moderate	1	No
Waterton River	2000	67%	N(80%); no forest(17%)	Moderate	2	No
Shaheeya Lake	910	83%	N(81%); no forest(17%)	Moderate	3	No

[1]N = no recorded fire activity.

Belly River Management Subdistrict

This subdistrict contains only the Belly River BMZ. The BMZ supports the third largest amount of potential habitat in the park (Table 3). Figure 8 provides general details for this subdistrict.

The two largest stand aggregates, on Lee Ridge and in the North Fork Belly River drainage, closely border the Blackfeet Indian Reservation and the Canadian border and are probably inappropriate to burn unless a cooperative effort is possible between the Park and the other respective agency. Four other stand aggregations of substantially smaller area are considered here, as well. These include the east and northeast sides of Cosley Ridge, the southwest side of Gable Mountain and the Redgap Creek drainage. According to present cover type most of these areas were poorly identified, with the exception of the Gable Mountain area (Table 5).

If a cooperative effort is plausible with either Parks Canada or the Blackfeet Indian Reservation, in relation to the two large aforementioned potential habitat, it is recommended that it be pursued with the latter group first. The potential habitat bordering the Blackfeet Indian Reservation, on Lee Ridge, is unquestionably the larger of the two. Fire evidence in this area suggests two stand replacing fires in the years 1859 and between 1859 and 1889 (Barrett 1997). The North Fork Belly River drainage experienced fire activity between 1859 and 1889, as well as 1761. The 1761 stand age is dominant in this drainage. Neither of the stand aggregates near Cosley Ridge had

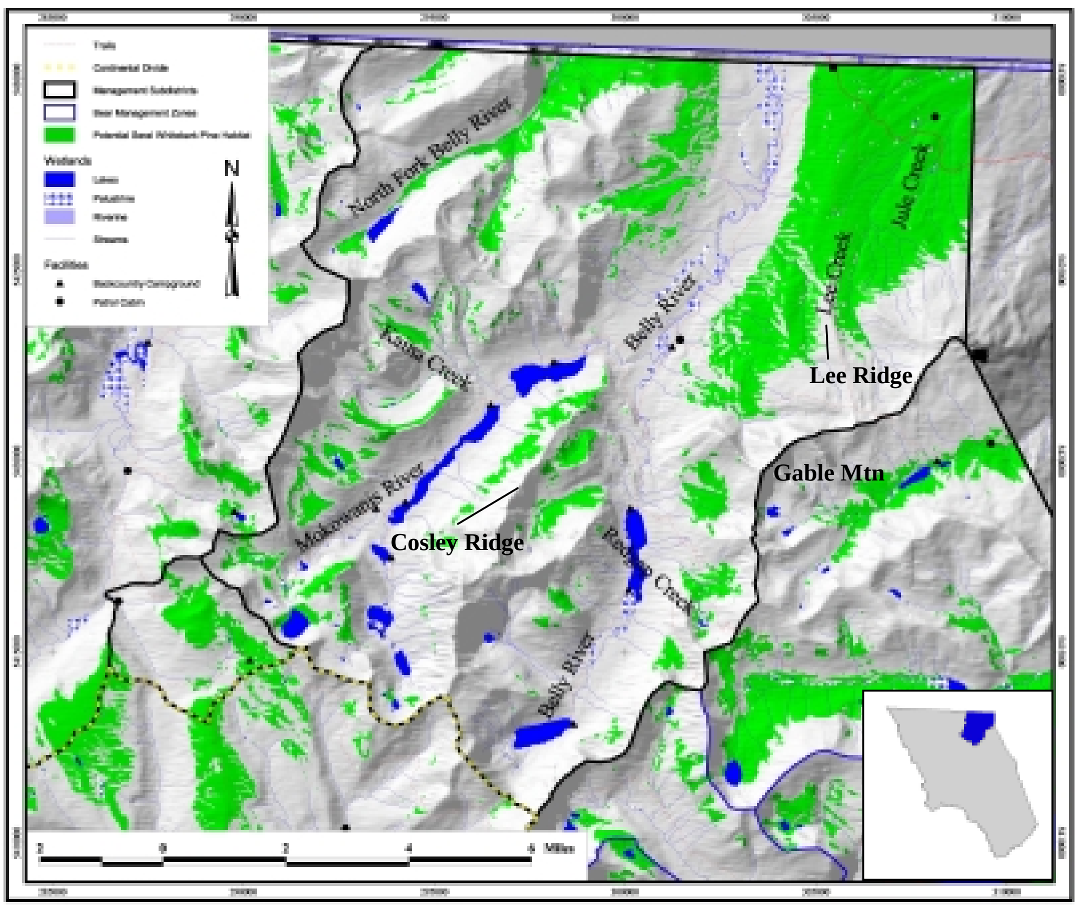

Figure 8. Hillshade image of Belly River subdistrict showing potential seral whitebark habitat.

evidence of recent fire activity. Both the Redgap Creek drainage and the Gable Mountain stand aggregate experienced fire activity in 1834. The Gable Mountain area, additionally, experience a stand replacing fire sometime between 1761 and 1794.

Accessibility is good in the Lee Ridge, Redgap Creek and North Fork Belly River areas and good to fair in the stand aggregate southwest of Gable Mountain. The stand aggregates to the east and northeast of Cosley Ridge are fair and fair to moderate in accessibility, respectively.

Primarily due to its high probability of occurrence and long time since last fire, the stand aggregate southwest of Gable Mountain has highest priority within the

Table 5. Priority statistics and information concerning stand aggregations within the Belly River subdistrict.

Stand Aggregate	Approx. Acreage	Relative Probability	Fire History	Relative Accessibility	Subdistrict Priority	Cooperation Needed
SW Gable Mtn	300	95%	1761-1794(73%); no forest(9%); 1834(9%)	Good - Fair	1	No
North Fork Belly River	2000	56%	no forest (30%); 1761(26%); 1859-1889(18%); N[1](16%)	Good	2	Yes
Lee Ridge	7900	54%	1859(38%); 1859-1889(35%);	Good	3	Yes
Redgap Creek	245	70%	N(47%); no forest(36%); 1834(7%)	Good	4	No
E Cosley Ridge	260	64%	no forest(75%); N(21%)	Fair	5	No
NE Cosley Ridge	160	54%	N(57%); no forest(36%)	Fair - Moderate	6	No

[1] No recorded fire activity.

subdistrict. The North Fork Belly River drainage is prioritized next. The optimal burn area is at the mouth of the drainage north of Sentinel Mountain and near the Canadian border. This area provides for a cooperative opportunity with Parks Canada. The Lee Ridge area follows in priority with the southwest portion of this stand aggregate as the best burn area. This southwest portion may be burned without fear of border trespass depending on weather and fuel conditions. The stand aggregates in the Redgap Creek drainage and on the east and northeast sides of Cosley Ridge are prioritized last, respectively.

Many Glacier Subdistrict

This area is commonly one of high day use and a beginning point for backpackers. It is also an area that contains a fairly high concentration of concessionaire operations. These facilities are concentrated at the mouth of several converging canyons (fig. 9).

Four areas contain a sizeable amount of potential whitebark pine habitat. The largest stand is found in the Kennedy Creek drainage, followed by stands on the north facing slope of Boulder Ridge, the Otatso Creek drainage and the Grinnell BMZ, respectively. The Boulder Ridge and Otatso Creek areas were fairly accurately identified (~70%), however, the Grinnell BMZ and Kennedy Creek drainage were poorly identified. Accessibility of all these areas are approximately the same – good or good to fair.

The Boulder Ridge area experienced fire activity between 1732 and 1794, 1834 and 1889, and in 1910. The Kennedy Creek drainage experienced fire activity in 1834

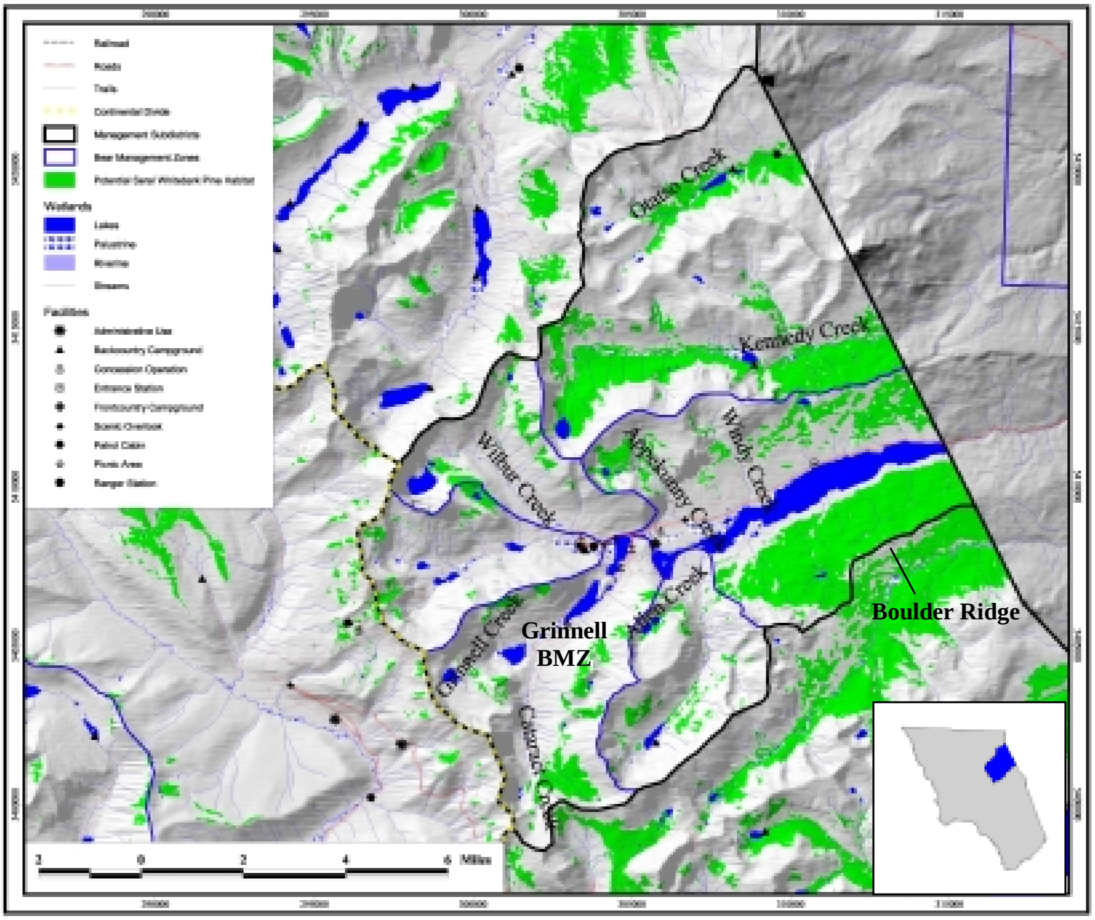

Figure 9. Hillshade image of the Many Glacier subdistrict showing potential seral whitebark habitat.

and 1921. Sometime between 1732 and 1761 a fire swept through the Otatso Creek drainage. In the potential habitat of Grinnell BMZ there is no apparent fire evidence.

All of these areas require a cooperative effort with the Blackfeet Indian Reservation, except for the Grinnell area. However, it may be feasible to contain a prescribed fire in the upper portion of Kennedy Creek. If a cooperative effort is possible these four areas are prioritized in the following order: Boulder Ridge, Otatso Creek drainage, Kennedy Creek drainage, and the Grinnell area (Table 6). Without a cooperative effort the latter area is the only possibility, however, it is not prioritized high park-wide.

Table 6. Priority statistics and information concerning stand aggregations within the Many Glacier subdistrict.

Stand Aggregate	Approx. Acreage	Relative Probability	Fire History	Relative Accessibility	Subdistrict Priority	Cooperation Needed
Boulder Ridge	4200	71%	1732-1794(23%); 1834-1889(18%); 1910(18%); no forest(14%)	Good - Fair	1	Yes
Otatso Creek	1000	74%	no forest(30%); 1732-1761(26%); N[1](20%)	Good	2	Yes
Kennedy Creek	4635	44%	N(34%); no forest(24%); 1921(11%); 1834(11%)	Good	3	Yes
Grinnell BMZ	980	49%	no forest(68%); N(27%)	Good - Fair	4	No

[1] No recorded fire activity.

St. Mary Subdistrict

The St. Mary subdistrict (fig. 10) holds both the greatest amount of potential habitat on both sides of the divide (Table 3) and perhaps the greatest opportunity for public outreach. Due to the amount of area contained within, the following areas are considered below: the Boulder Creek drainage, the Divide Creek drainage (including northwest facing slope to the north of this drainage), the Siyeh Creek drainage, and the drainage south of Heavy Runner Mountain (Table 7). According to the covertype data, the Divide Creek drainage is the most accurate followed by Siyeh and Boulder Creek drainages and finally the Heavy Runner Mountain area within the subdistrict.

The Siyeh Creek drainage, in the northwestern part of this subdistrict, provides a great opportunity for public outreach. The basin contains the third largest stand of potential habitat in the subdistrict. Moreover, Going-to-the-Sun Road runs by this drainage with a couple of pullouts that provide good glimpses into the drainage. Trails

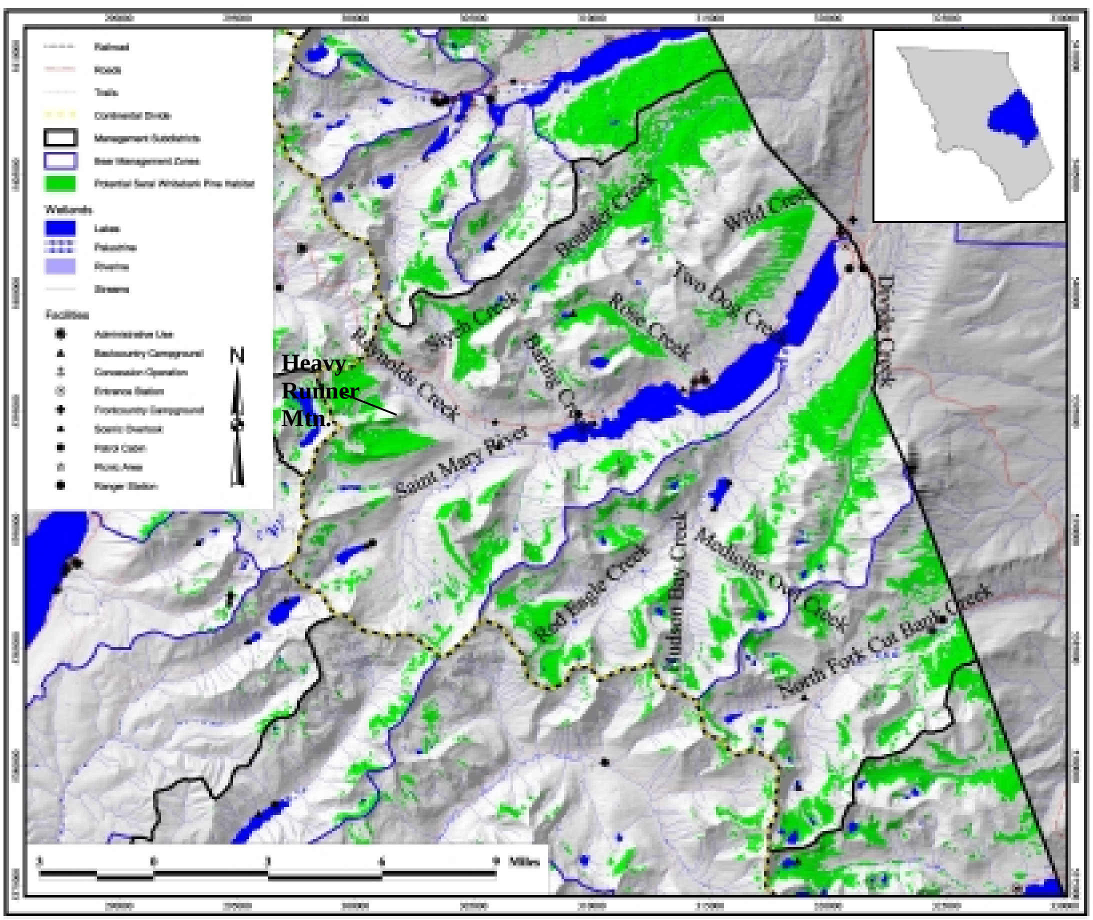

Figure 10. Hillshade image of the St. Mary subdistrict showing potential seral whitebark habitat.

pass directly through whitebark pine habitat, making it the most accessible of any in this subdistrict. This drainage experienced two stand-replacing fires in 1732 and 1844, though very little of these fires affected the potential habitat. The Siyeh Creek drainage

Table 7. Priority statistics and information concerning stand aggregations within the St. Mary subdistrict.

Stand Aggregate	Approx. Acreage	Relative Probability	Fire History	Relative Accessibility	Subdistrict Priority	Cooperation Needed
Divide Creek	3715	89%	1732-1794(53%); N[1](25%); no forest(10%)	Good - Fair	1	Yes
Siyeh Creek	980	73%	No Forest(52%); N(40%)	Good	2	No
Boulder Creek	4200	71%	1732-1794(23%); 1834-1889(18%); 1910(18%); no forest(14%)	Good - Fair	3	Yes
South of Heavy Runner Mtn	1140	60%	No Forest(53%); N(42%)	Fair - Moderate	4	No

[1] No recorded fire activity.

is prioritized very high in the park, but just below the Divide Creek drainage if a cooperative effort with the Blackfeet Indian Reservation is possible.

The Boulder Creek drainage experienced fire activity sometime between 1732 and 1794, between 1834 and 1889, and in 1910; most of the fire activity occurring in the first time period. The area in the Divide Creek drainage experienced fire activity sometime between 1732 and 1794. Approximately 25 percent of this area, however, has not experienced recent fire activity. The potential habitat south of Heavy Runner Mountain has no apparent recent fire activity. Accessibility to the Divide Creek area and Boulder

Creek drainage is good to fair. The area south of Heavy Runner Mountain is rated as fair to moderate, however, on topographic maps and aerial photographs it appears rather difficult to access.

Within the subdistrict the Divide Creek drainage is prioritized highest followed by the Siyeh and Boulder Creek drainages and Heavy Runner Mountain area (Table 7). However, if a cooperative effort is not feasible, the Siyeh drainage is of high priority followed by the Heavy Runner Mountain area.

Two Medicine Subdistrict

Within the Two Medicine subdistrict (fig. 11) there are two BMZs – Two Medicine and Lubec. In addition to a heavy density, the Two Medicine BMZ supports the fourth largest amount of potential habitat, while Lubec BMZ is in the lower end of the spectrum (table 3). Within the Two Medicine BMZ the Lake Creek, Dry Fork, and Forty and Fortyone Mile Creek drainages contain the greatest amount of potential habitat, respectively. However, Bighorn Basin holds the largest contiguous stand of seral whitebark pine (table 8). The present covertype map suggests that the stand aggregates in the Dry Fork drainage and in Bighorn Basin are more likely to be seral whitebark pine stands.

The Dry Fork drainage experienced two stand-replacing fires, in 1919 and 1761, with the majority of potential habitat falling within the 1919 burn (Barrett 1993). Although the vegetation is fairly sparse in the lower, eastern part of the drainage, there may be potential for fire escape which could reach the Blackfeet Indian Reservation. The majority of vegetation in the lower portion of Bighorn Basin has not experienced a fire since 1715, almost 285 years ago. The Lake Creek drainage has a fire history similar to that of the Dry Fork drainage. Most of the vegetation within the Forty and Fortyone Mile Creeks drainage has not experienced a fire since 1875. Both of the latter drainages are in close proximity to the Blackfeet Indian Reservation and therefore have greater potential for fire escape into this area.

Accessibility to and within the Dry Fork drainage is good, as it is within the Forty and Fortyone Mile Creeks drainage. Due to its slope, the Bighorn Basin is a little less

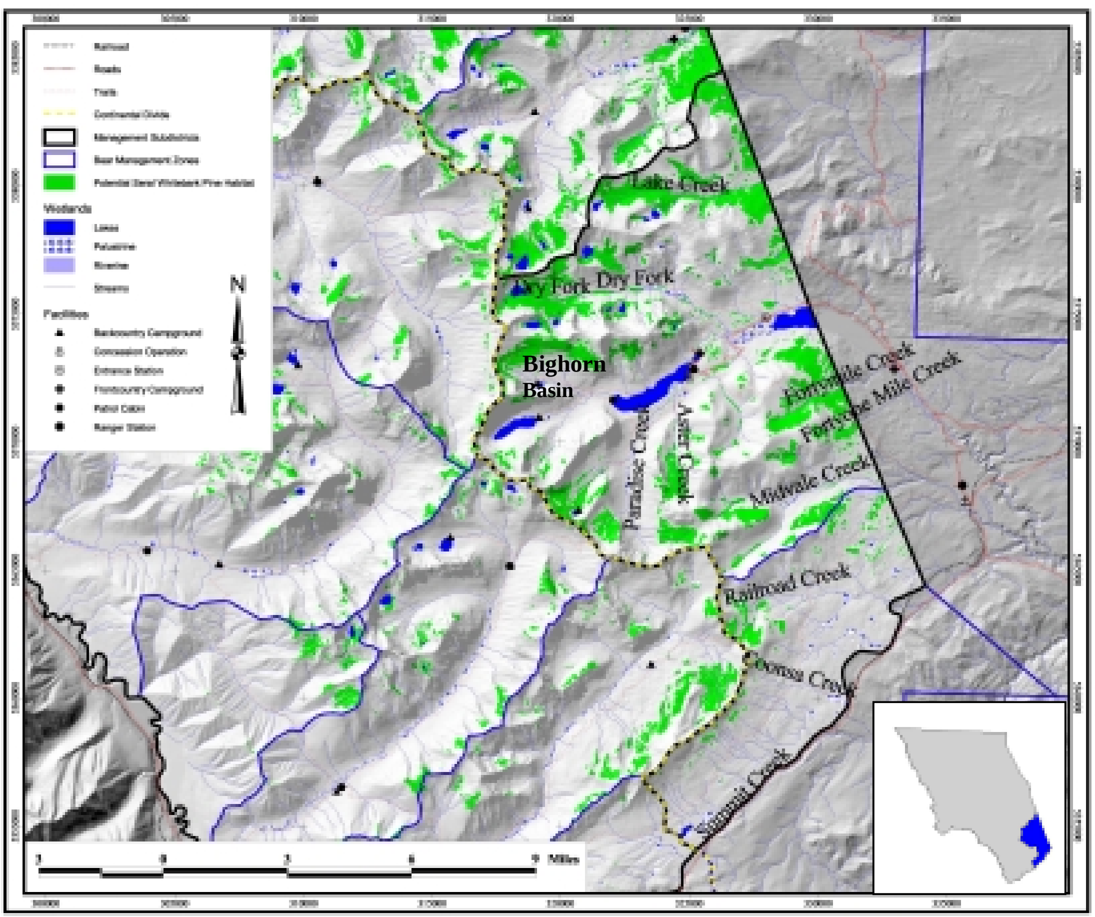

Figure 11. Hillshade image of the Two Medicine subdistrict showing potential seral whitebark habitat.

accessible than within the Dry Fork drainage. However, it is closer to a trailhead. The Lake Creek drainage has moderate to poor accessibility.

Table 8. Priority statistics and information concerning stand aggregations within the Two Medicine subdistrict.

Stand Aggregate	Approx. Acreage	Relative Probability	Fire History	Relative Accessibility	Subdistrict Priority	Cooperation Needed
Dry Fork	1530	69%	Non-seral(39%); 1919(29%); 1761(19%)	Good - Fair	1	No
Lake Creek	1380	67%	1829(36%); 1919(33%); Non-seral(16%)	Moderate	2	Yes
Bighorn Basin	665	59%	Non-seral(80%); pre1778(14%)	Good - Fair	3	No
Forty and Fortyone Mile Creeks	1400	58%	Non-seral(69%); 1855(14%); 1918 (10%)	Good	4	Yes

The Dry Fork drainage is worthy of consideration for a burn targeting only whitebark pine at the most upper, western reaches of the drainage. Otherwise, due to the relative recentness of the last stand-replacement fire (1919), this drainage is prioritized low. Due to the lack of recent fire activity within the Bighorn Basin, this drainage is prioritized higher.

West Side Prioritization

The major subdistricts on the west side of the divide, particularly the North and Middle Fork subdistricts, are much larger in comparison to the east side subdistricts (Table 3). Therefore, for the sake of simplicity and brevity only a select few stand aggregations in these subdistricts are discussed below. The stand aggregates not discussed here are of low to moderate priority in relation to those considered.

North Fork Subdistrict

Logging BMZ

This BMZ hosts three stand aggregates worthy of consideration (figure 12). These stand aggregates are found on or in the cirque south of Mt. Geduhn, the west side of Trapper Peak, and the west slope of Mt. Geduhn, in descending order of area. The probabilities of occurrence of the latter two areas are very high (table 9). The probability of the first stand aggregate is poor, however, its large stand size counters this deficiency.

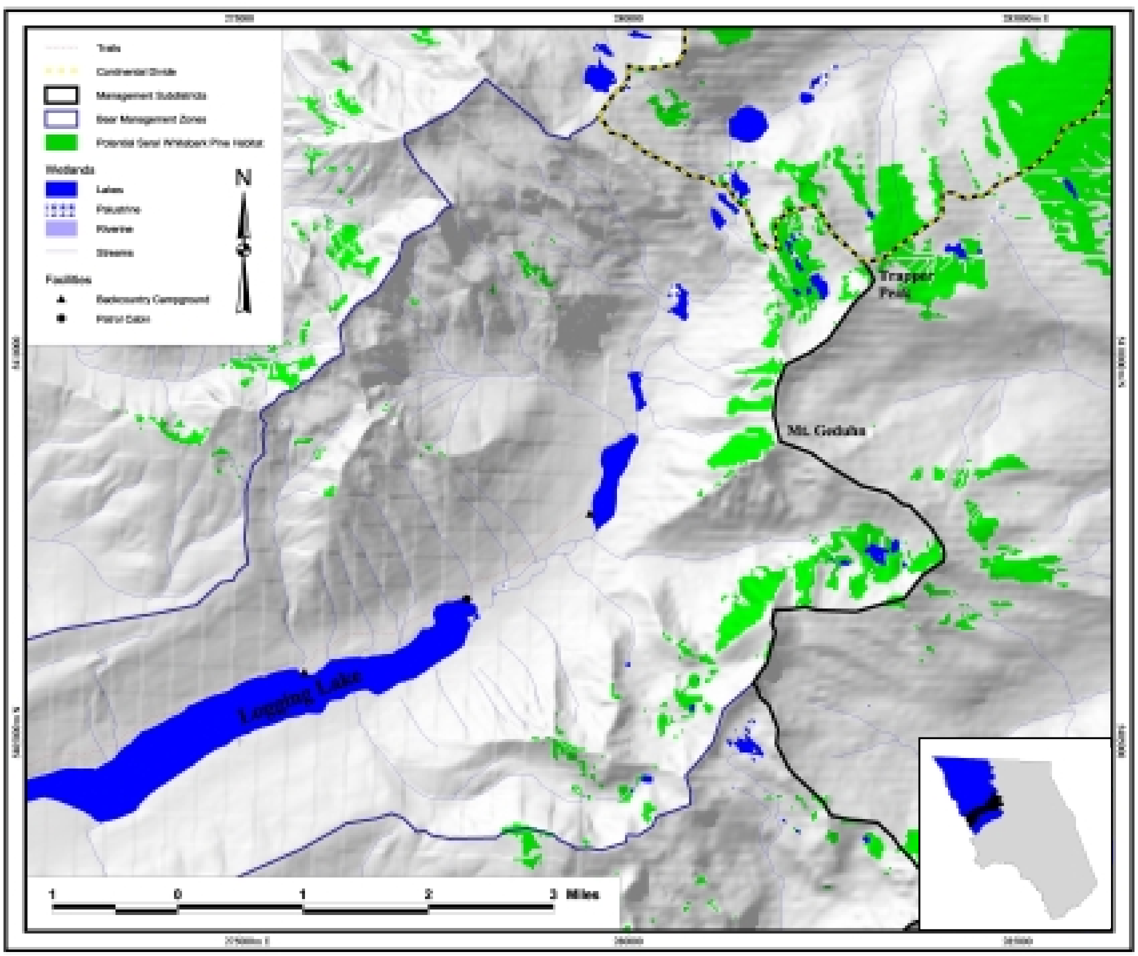

Figure 12. Hillshade image of the Logging Lake BMZ within the North Fork subdistrict showing potential seral whitebark habitat.

Both of the Mt. Geduhn stand aggregates experienced fire activity before 1844, between 1844 and 1910, and in 1910. The Trapper Peak was identified mostly as barren land, however, aerial photographs and personal experience indicate that this area is comprised dominantly of seral whitebark pine stands. Accessibility to these areas is moderate at best and is very difficult on the west slope of Mt. Geduhn, as suggested by aerial photographs.

Table 9. Priority statistics and information concerning stand aggregations within the Logging BMZ.

Stand Aggregate	Approx. Acreage	Relative Probability	Fire History	Relative Accessibility	BMZ Priority	Cooperation Needed
South of Mt. Geduhn	280	67%	barren(59%); 1910(7%); pre-1844 and 1844-1910(6%)	Moderate	1	No
West of Trapper Peak	183	99%	barren(76%); water(13%); N[1](6%)	Moderate	2	No
West Slope of Mt. Geduhn	110	100%	barren(47%); water(24%); 1910(12%); pre-1844 and 1844-1910(10%)	Moderate	3	No

[1] No recorded fire activity.

This area is prioritized primarily based on total area. The cirque to the south of Mt. Geduhn is prioritized first, followed by the west side of Trapper Peak and the west slope of Mt. Geduhn, respectively. None of these areas require outside agency cooperation.

Kintla BMZ

There are three stand aggregates within the Kintla BMZ (fig. 13) worthy of consideration. These areas include, in descending order of total acreage, north and west of Boulder Pass, and the north sides of Kinnerly and Parke Peaks. All three of these areas have a high probability of occurrence (table 10).

The two stand aggregates north of the peaks experienced fire activity in 1889 and between 1844 and 1910. The fire history data show most of the Boulder Pass area as

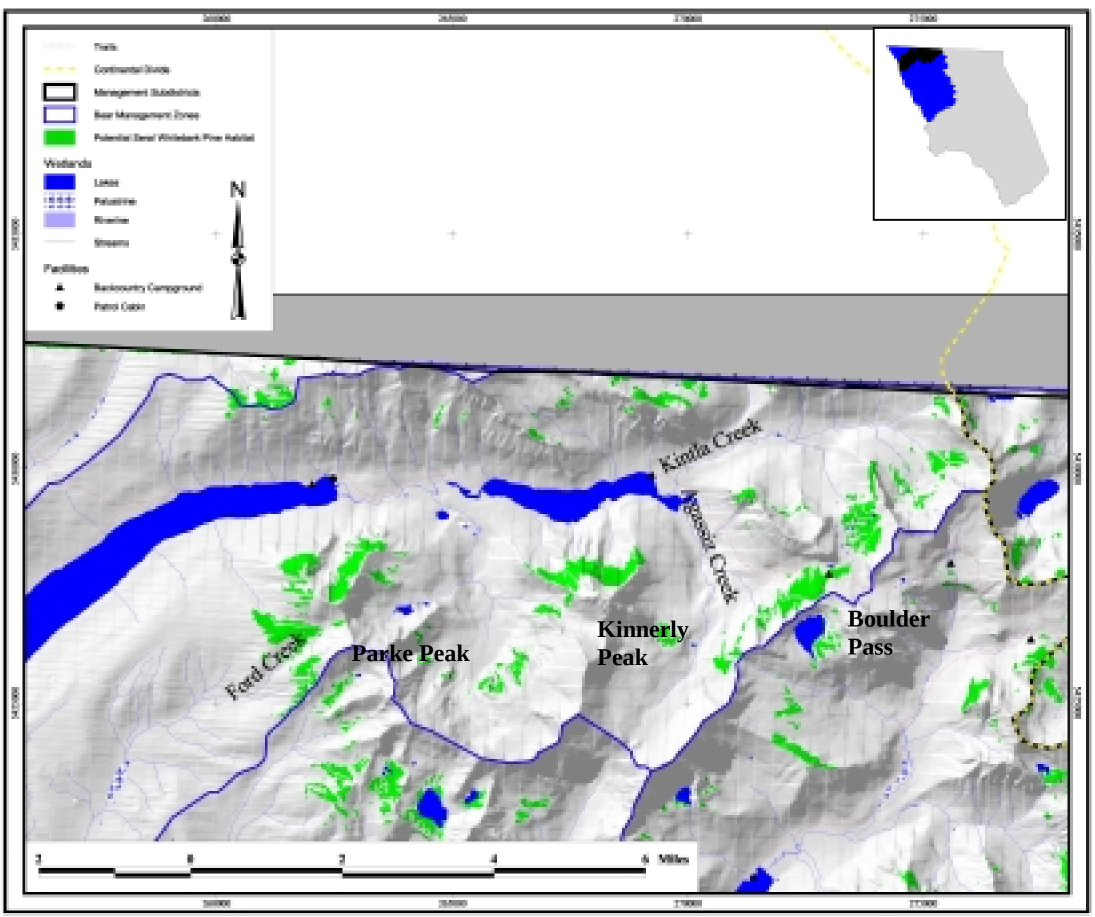

Figure 13. Hillshade image of the Kintla BMZ within the North Fork subdistrict showing potential seral whitebark habitat.

barren. According to aerial photographs, this information appears fairly accurate, particularly for the stands to the north. However, the stands to the west of Boulder Pass are very worthy of a prescribed fire and much of it has not experienced fire activity since 1885. Accessibility is moderate to the Parke and Kinnerly Peak areas and good to fair to the Boulder Pass area.

Table 10. Priority statistics and information concerning stand aggregations within the Kintla BMZ.

Stand Aggregate	Approx. Acreage	Relative Probability	Fire History	Relative Accessibility	BMZ Priority	Cooperation Needed
North and West of Boulder Pass	315	98%	barren(94%); 1885(<1%)	Good - Fair	1	No
North of Kinnerly Peak	194	98%	barren(62%); 1889(18%); 1844-1910(13%)	Moderate	2	No
North of Parke Peak	120	95%	barren(40%); 1889(23%); 1844-1910(27%)	Moderate	3	No

The primary factor affecting the prioritization of these stands is their total area. The stand aggregates are prioritized as follows: the Boulder Pass area, the Kinnerly Peak area, and the Parke Peak area. None of these areas require outside agency cooperation.

Quartz BMZ

Although three stand aggregations are discussed below only one of these is worth consideration, that of the upper Quartz Creek drainage (fig. 14). The other two stand aggregates include those south of Square Peak and north of Logging Mountain. These

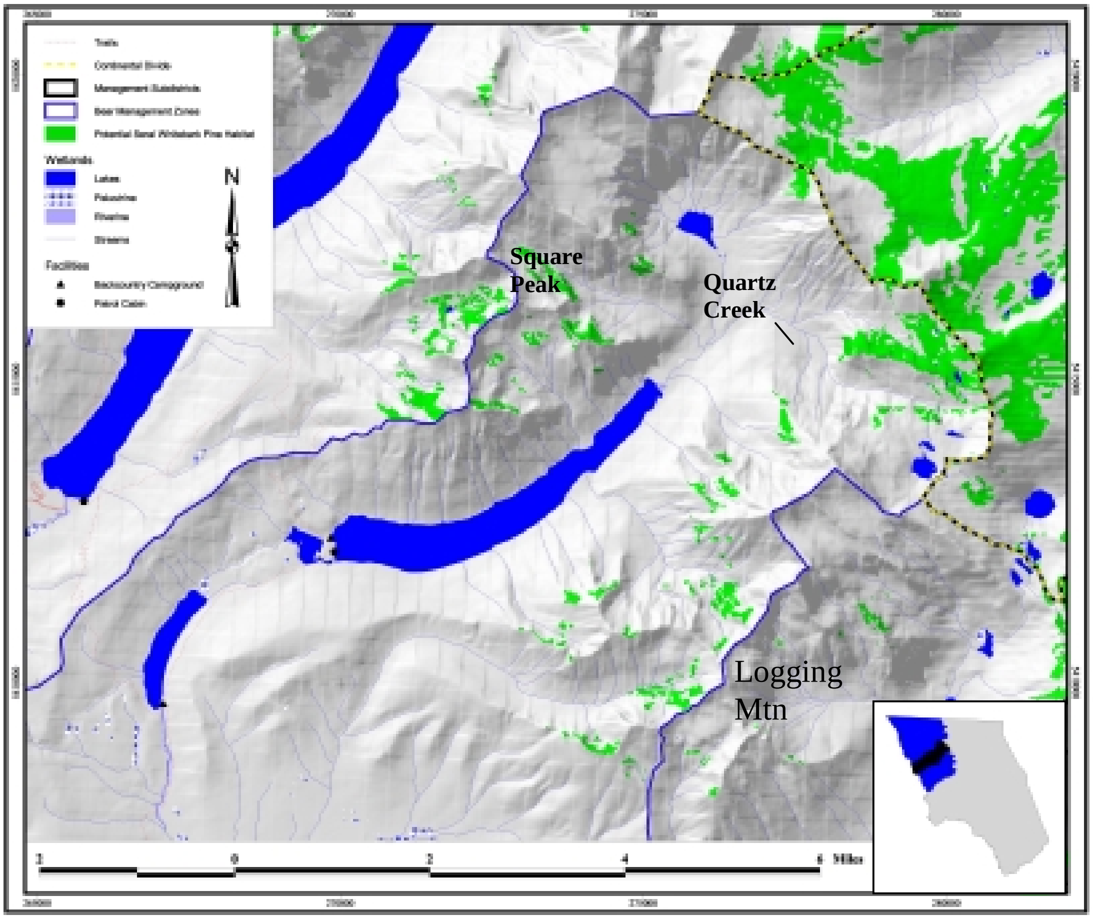

Figure 14. Hillshade image of the Quartz BMZ within the North Fork subdistrict showing potential seral whitebark habitat.

latter two areas contain relatively little potential habitat and their occurrences are less probable (table 11).

Otherwise, the three areas have experienced similar fire histories and are approximately equally accessible. All have experienced fire activity in 1869 and 1889. Both the upper Quartz Creek drainage and the area north of Logging Mountain are moderately accessible, while the stand aggregates south of Square Peak are fair to moderate in accessibility.

Table 11. Priority statistics and information concerning stand aggregations within the Quartz BMZ.

Stand Aggregate	Approx. Acreage	Relative Probability	Fire History	Relative Accessibility	BMZ Priority	Cooperation Needed
Upper Quartz Creek	440	100%	barren(70%); 1889(9%); 1869(6%)	Moderate	1	No
South of Square Pk.	79	73%	barren(70%); 1889(9%); 1869(6%)	Fair - Moderate	2	No
North of Logging Mtn.	71	87%	barren(78%); 1889(11%); 1869(7%)	Moderate	3	No

The potential habitat within the upper Quartz Creek drainage is prioritized highest. The Square Peak and Logging Mountain areas are prioritized much lower, respectively. None of these areas require cooperation with other agencies.

Bowman BMZ

There are three areas considered below for the Bowman BMZ (fig. 15). These areas include, in order of descending acreage and probability of occurrence, the Jefferson Creek drainage, the area southwest of Square Peak, and the Pocket Creek drainage (table 12).

Little fire activity has recently occurred within these areas. The Square Mountain area experienced a stand replacement fire in 1889. Accessibility to the Pocket Creek drainage is fair, to the Square Peak area is fair to moderate, and to the Jefferson Creek drainage is moderate.

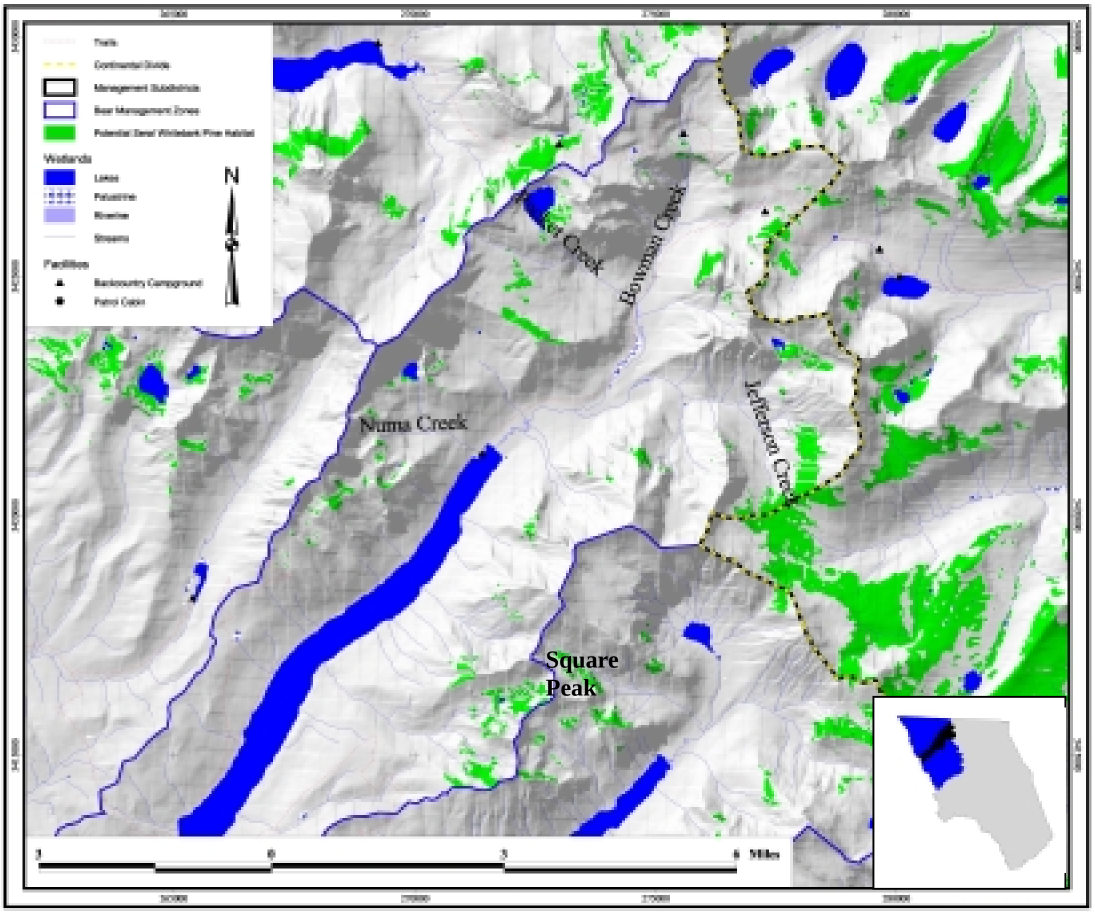

Figure 15. Hillshade image of the Bowman BMZ within the North Fork subdistrict showing potential seral whitebark habitat.

Prioritization follows the order of total area and probabilities of each stand aggregate. The Jefferson Creek drainage is prioritized first, followed by the Square Peak area and the Pocket Creek drainage, respectively. There is no need for outside agency cooperation for prescribed fire in any of these areas.

McDonald and Hidden Subdistricts

Due to the 1998 fires, two large areas of potential habitat, found in the north of McDonald subdistrict (fig. 16) on Flattop and West Flattop Mountains, are not considered

Table 12. Priority statistics and information concerning stand aggregations within the Bowman BMZ.

Stand Aggregate	Approx. Acreage	Relative Probability	Fire History	Relative Accessibility	BMZ Priority	Cooperation Needed
Jefferson Creek	200	98%	barren(81%); N[1](6%); hs noburn[2](5%)	Moderate	1	No
Southwest of Square Peak	178	92%	barren(78%); 1889(10%)	Fair - Moderate	2	No
Pocket Creek	133	74%	barren(62%); hs burn[3](33%)	Fair	3	No

[1] No recorded fire activity.
[2] Herbaceous or shrub not recently burned.
[3] Herbaceous or shrub burned.

in the subsequent prioritization. These areas, however, provide a unique opportunity to monitor the potential regeneration of whitebark pine, both natural and artificial, within the park. Furthermore, it provides an opportunity to test and modify the identification and prioritization performed herein.

Four stand aggregates are considered below for the McDonald and Hidden subdistricts. These include, in descending order of total area, the Hidden Lake drainage, the northwest slope of Mt. Brown, the upper Dutch Creek drainage, and the northwest slope of Mt. Cannon. All of these stand aggregates have a relatively high probability of occurrence (table 13).

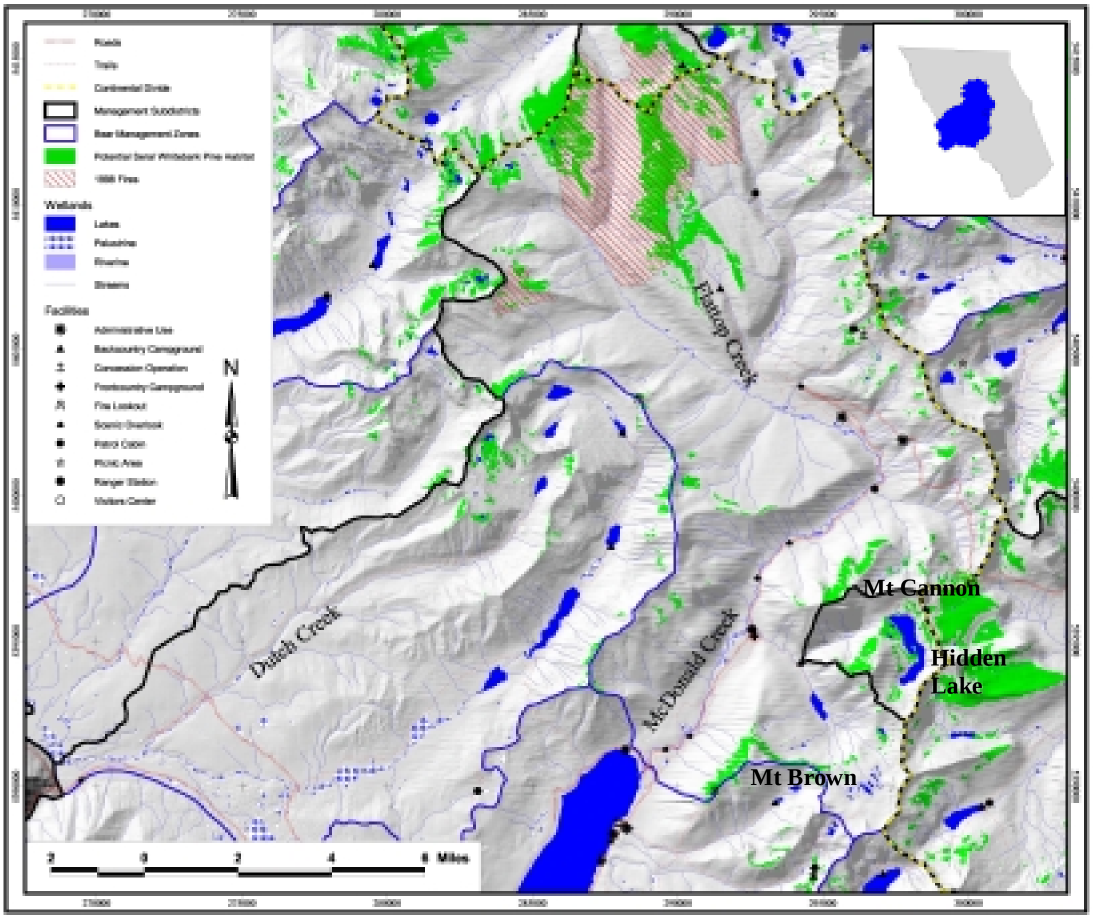

Figure 16. Hillshade image of the McDonald and Hidden subdistricts showing potential seral whitebark habitat.

Both the Mt. Brown area and the Hidden Lake drainage are classified as barren according to Barrett's fire history maps. However, aerial photographs show these areas to indeed be forested. The Mt. Cannon area experienced fire activity before 1844 and between 1844 and 1910. The stand age of the upper Dutch Creek drainage is more recent, with fires in 1918 and 1920. Accessibility appears best to the Hidden Lake drainages. The upper Dutch Creek drainage and the Mt. Brown area follow in accessibility. The Mt. Cannon area is of moderate accessibility.

Table 13. Priority statistics and information concerning stand aggregations within the McDonald and Hidden subdistricts.

Stand Aggregate	Approx. Acreage	Relative Probability	Fire History	Relative Accessibility	Subdistrict Priority	Cooperation Needed
Hidden Lake	415	98%	barren(96%)	Good - Fair	1	No
Mt. Brown	347	88%	barren(90%); N[1](8%)	Fair	2	No
Mt. Cannon	260	99%	barren(95%); pre-1844 and 1844-1910(3%)	Moderate	3	No
Upper Dutch Creek	313	87%	barren(81%); 1920(11%); 1918(7%)	Fair	4	No

[1] No recorded fire activity.

The Hidden Lake drainage recieves the highest priority within both subdistricts. In addition to the large total area and high probability of occurrence, it boasts an incredible opportunity for public outreach. The Hidden Lake trail, much of which looks down upon much of this potential habitat, is one of the most highly used in the park. This potential habitat is perhaps the most visible and is one of the larger stand aggregates of any in the park. Priorities continue in the following order, the northwest side of Mt. Brown, the northwest side of Mt. Cannon, and the upper Dutch Creek drainage.

Middle Fork Subdistrict

Nyack BMZ

Within the Nyack BMZ (fig. 17) there are four stand aggregates considered. These stand aggregates include, the Thompson and Stimson Creek drainages, and the basins northwest and southwest of McClintock Peak. The basin northwest of McClintock Peak contains the greatest total area of potential habitat followed by the Thompson Creek

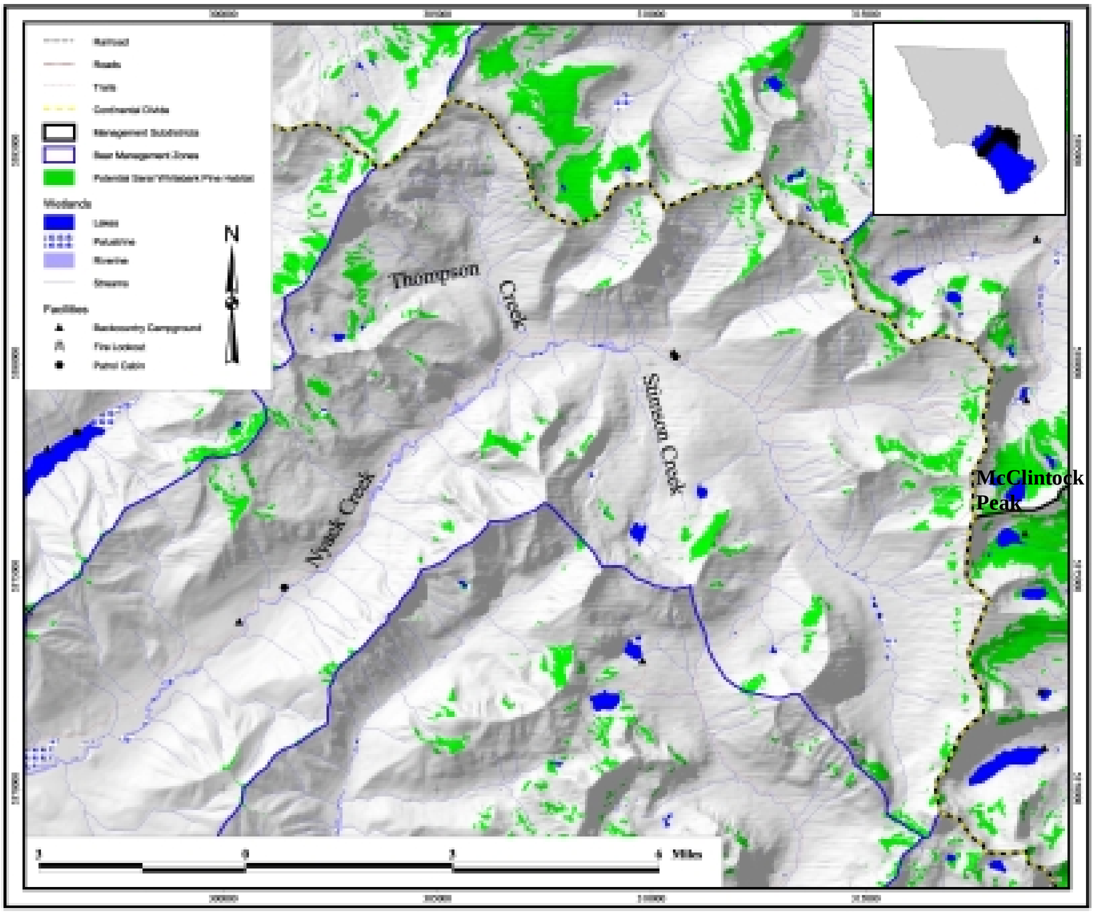

Figure 17. Hillshade image of the Nyack BMZ within the Middle Fork subdistrict showing potential seral whitebark habitat.

drainage, the basin southwest of McClintock Peak, and the Stimson Creek drainage, respectively (table 14). Their probabilities of occurrence follow approximately the same order.

According to the fire history map only the basin southwest of McClintock Peak has experienced recent fire activity, the others were classified as barren. Aerial photographs, however, suggest that these areas are forested. The southwest basin of McClintock Peak experienced fire activity before 1844 and sometime between 1844 and

1910. Relative accessibility for the Thompson Creek drainage is moderate, fair to moderate for the Stimson Creek drainage and good to fair for both basins near McClintock Peak.

Priorities follow the total acreage and probabilities of occurrence closely. The Stimson Creek drainage is prioritized much lower overall than is suggested by the table due to its low probability of occurrence. There is no necessity for a cooperative effort with an outside agency for any of these areas.

Table 14. Priority statistics and information concerning stand aggregations within the Nyack BMZ.

Stand Aggregate	Approx. Acreage	Relative Probability	Fire History	Relative Accessibility	BMZ Priority	Cooperation Needed
Northwest of McClintock Pk	229	100%	barren(72%); N[1](20%)	Good - Fair	1	No
Thompson Creek	180	95%	barren(95%)	Moderate	2	No
Southwest of McClintock Pk	119	97%	barren(35%); pre-1844 and 1844-1910(25%); N(21%)	Good - Fair	3	No
Stimson Creek	116	45%	barren(75%); N(8%)	Fair - Moderate	4	No

[1] No recorded fire activity.

Coal BMZ

There are three stand aggregates of note in the Coal BMZ (fig. 18). These include, in descending order of total area, the northwest sides of Lone Walker Mountain and Caper Peak, the Buffalo Woman Lake drainage, and the south side of Mt. Pinchot.

The probabilities of occurrence for the first and last areas are very high, while that of the second area is moderate (table 15).

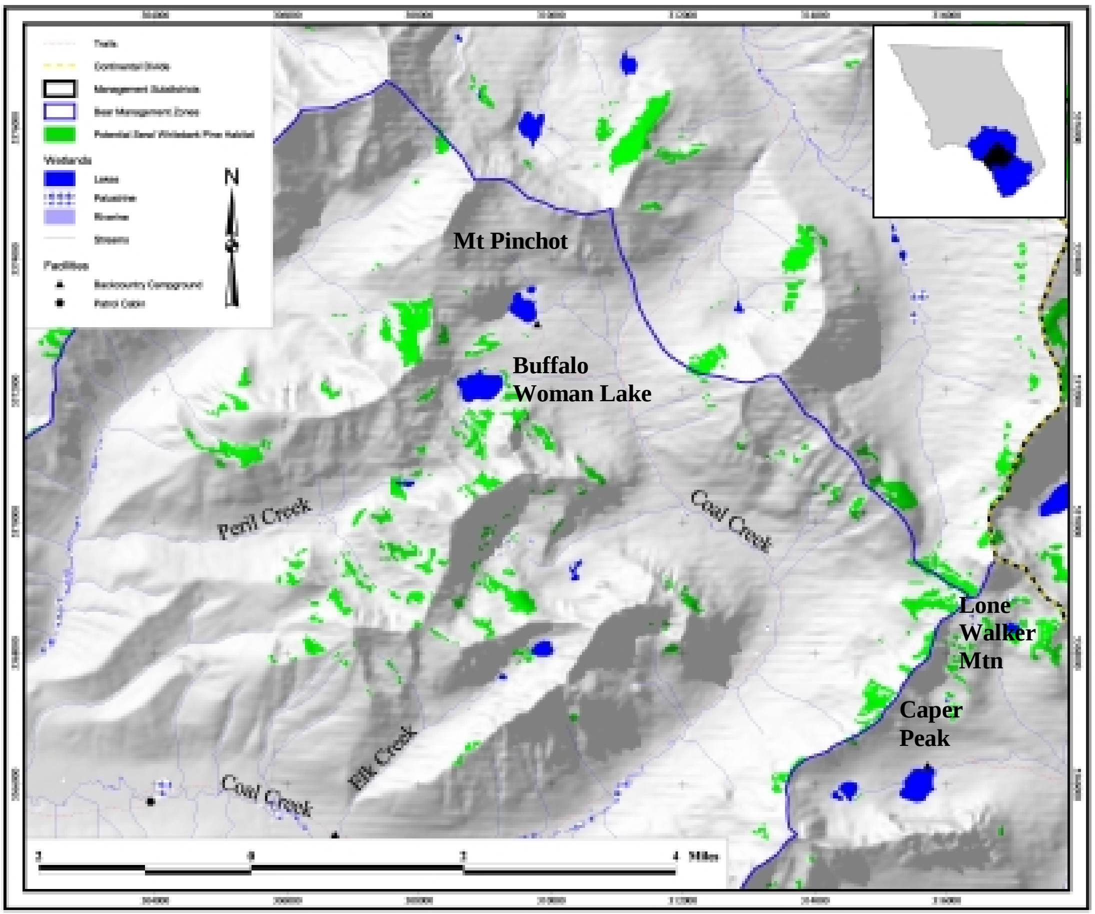

Figure 18. Hillshade image of the Coal BMZ within the Middle Fork subdistrict showing potential seral whitebark habitat.

The fire histories of these stand aggregates are mixed. The Mt. Pinchot area experienced fire activity in 1910. The Buffalo Woman Lake drainage stand aggregates are older than 1910. The Lone Walker Mountain/Caper Peak area experienced fire activity before 1844, as well as, sometime between 1844 and 1910. Accessibility to the Mt. Pinchot and Lone Walker Mountain/Caper Peak areas is fair to moderate. The

Table 15. Priority statistics and information concerning stand aggregations within the Coal BMZ.

Stand Aggregate	Approx. Acreage	Relative Probability	Fire History	Relative Accessibility	BMZ Priority	Cooperation Needed
Lone Walker Mtn to Caper Pk	173	98%	barren(53%); N[1](20%); pre-1844 and 1844-1910(10%)	Fair - Moderate	1	No
Buffalo Woman Lake	148	75%	barren(60%); X910[2](13%)	Good - Fair	2	No
South of Mt. Pinchot	104	100%	barren(61%); 1910(22%); hs noburn[3](10%); hs burn[4](6%)	Fair - Moderate	3	No

[1] No recorded fire activity.
[2] Before 1910.
[3] Herbaceous or shrub not burned.
[4] Herbaceous or shrub burned.

Buffalo Woman Lake drainage has good to fair accessibility. With similar fire histories these stands are prioritized primarily based on size. The Lone Walker Mountain/Caper Peak area is prioritized first, followed by the Buffalo Woman Lake drainage and Mt. Pinchot area, respectively. None of these areas require cooperation with outside agencies.

Muir BMZ

Three stand aggregates are considered below for the Muir BMZ (fig. 19). Two stand aggregates are located off of Mount St. Nicholas, to the west and the southeast, and another to the southwest of Salvage Mountain. The west Mount St. Nicholas stand aggregate contains the greatest total area, followed by the Salvage Mountain stand and

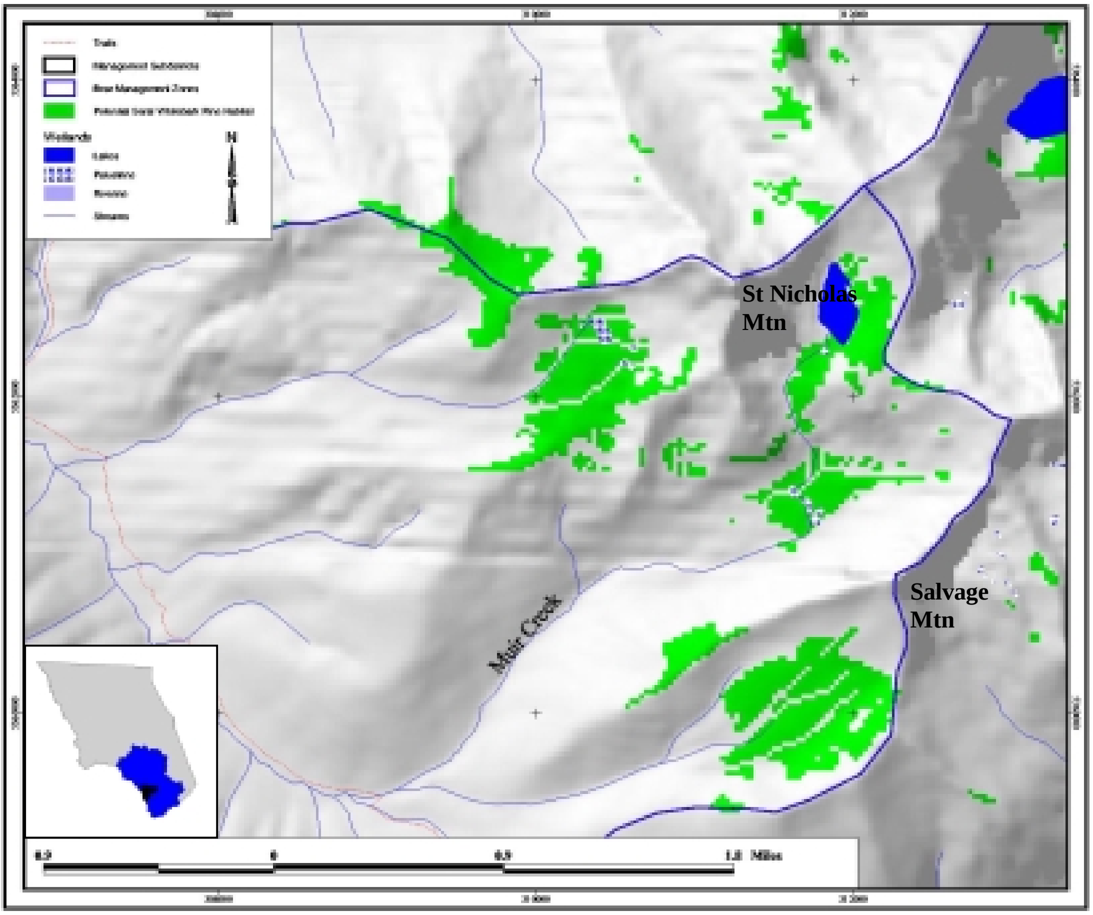

Figure 19. Hillshade image of the Muir BMZ within the Middle Fork subdistrict showing potential seral whitebark habitat.

the second St. Nicholas stand, respectively. Their probabilities of occurrence follow the reverse order, but are all high (table 16).

The potential habitat within these areas appears to be some of the older within the park. The stand aggregates west of Mount St. Nicholas last experienced fire in 1720. The Salvage Mountain habitat is classified around 1843. Much of the southeast Mount St. Nicholas stand aggregate is classified according to the fire history map as barren, shrub, or herbaceous. However, aerial photographs suggest this area to be forested, though not as continuous as the other two areas. This later area is moderately accessible. The former two areas are fair to moderately accessible.

Priorities proceed as the following: the west stand aggregates of Mount St.

Table 16. Priority statistics and information concerning stand aggregations within the Muir BMZ.

Stand Aggregate	Approx. Acreage	Relative Probability	Fire History	Relative Accessibility	BMZ Priority	Cooperation Needed
West of Mt. St. Nicholas	207	81%	1720(47%); barren(31%); hs noburn[1](10%)	Fair - Moderate	1	No
Southwest of Salvage Mtn	170	90%	probably1843(51%); barren(27%); hs noburn(9%); hsburn[2](8%)	Fair - Moderate	2	No
Southeast of Mt. St. Nicholas	136	98%	barren(54%); hs noburn(13%); hs burn(9%)	Moderate	3	No

[1] Herbaceous or shrub not burned.
[2] Herbaceous or shrub burned.

Nicholas, the southwest of Salvage Mountain, and the southeast of Mount St. Nicholas. None of these areas require a cooperative effort with outside agencies.

Park BMZ

Four stand aggregates are considered below for priority within the Park BMZ (fig. 20). These include, in descending order of total potential habitat area, Rotunda Cirque, south of Lone Walker Mountain, northwest of Mt. Despair, and north of Soldier and Sheep Mountains. Probabilities of occurrence are all fairly high for these areas (table 17).

Both Rotunda Cirque and the area northwest of Mt. Despair is classified as barren, shrub, or herbaceous according to the fire history map. Rotunda Cirque, however, is forested, as suggested by aerial photographs. The Mt. Despair area does appear sparsely forested, particularly on the east side of ridge. The stand aggregate south of Lone Walker Mountain is sparsely forested as well, however, fire activity occurred here before 1844 and sometime between 1844 and 1910. The Soldier/Sheep Mountains area has not experienced fire activity since approximately 1615. Accessibility is fair in all

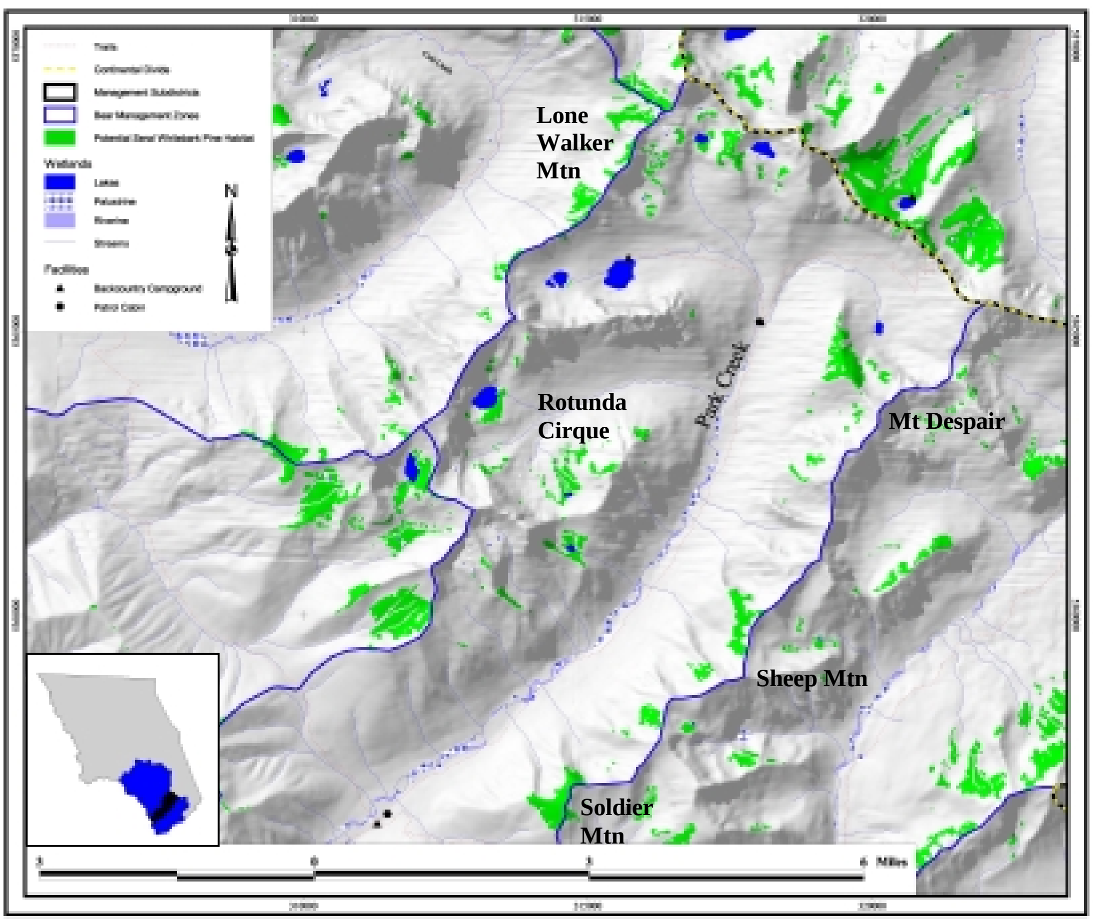

Figure 20. Hillshade image of the Park BMZ within the Middle Fork subdistrict showing potential seral whitebark habitat.

Table 17. Priority statistics and information concerning stand aggregations within the Park BMZ.

Stand Aggregate	Approx. Acreage	Relative Probability	Fire History	Relative Accessibility	BMZ Priority	Cooperation Needed
Soldier and Sheep Mtn.	105	86%	probably1615(45%); barren(40%); hs noburn[1](10%)	Fair	1	No
Rotunda Cirque	135	99%	barren(44%); N[2](40%); hs noburn(8%)	Fair - Moderate	2	No
Northwest of Mt. Despair	105	100%	barren(61%); N(15%); hs noburn(14%)	Fair	3	No
South Lone Walker Mtn.	111	86%	barren(67%); pre-1844 and 1844-1910(11%); N(10%)	Fair	4	No

[1] Herbaceous or shrub not burned.
[2] No recorded fire activity.

areas except the Rotunda Cirque, which is fair to moderate in accessibility.

Primarily due to its lack of fire activity in the last 384 years, the Soldier/Sheep Mountains area is prioritized first. The Rotunda Cirque is prioritized next, followed by the northwest area of Mt. Despair and the area south of Lone Walker Mountain. None of these areas require outside agency cooperation.

Ole BMZ

The Ole BMZ (fig. 21) hosts a couple of the largest stand aggregates found on the west side of the park. Four of these stands are considered below. These stand aggregates include, in descending order of total area, the area north and west of Summit Mountain, the Debris Creek drainage, the area northwest of Running Rabbit Mountain, and the

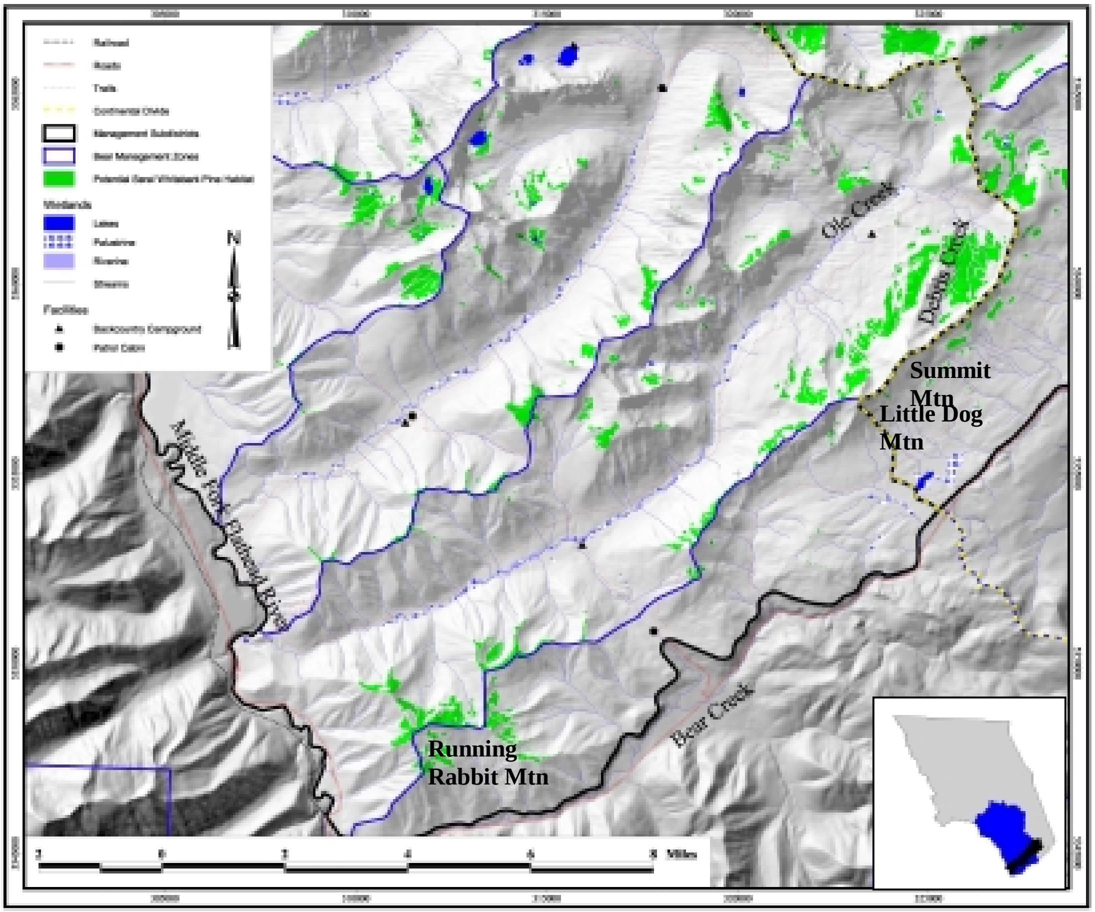

Figure 21. Hillshade image of the Ole BMZ within the Middle Fork subdistrict showing potential seral whitebark habitat.

northwest of Little Dog Mountain. All of these areas have high probabilities of occurrence (table 18).

Both the Debris Creek drainage and the area northwest of Little Dog Mountain are classified as not experiencing recent fire activity. However, aerial photographs suggest that these areas are forested. The Summit and Running Rabbit Mountain areas experienced fire activity in 1910. The later area additionally experienced fire activity sometime prior to 1910. Accessibility is fair to the Summit and Little Dog Mountain areas, good to fair to the Debris Creek drainage, and moderate to the Running Rabbit Mountain area.

Priorities follow closely the amounts of total stand aggregate area. These priorities proceed as follows, the Summit Mountain area, the Debris Creek drainage, the Running Rabbit Mountain area, and the Little Dog Mountain area. None of these areas require a cooperative effort with an outside agency, with the possible exception of the Running Rabbit Mountain area.

Table 18. Priority statistics and information concerning stand aggregations within the Ole BMZ.

Stand Aggregate	Approx. Acreage	Relative Probability	Fire History	Relative Accessibility	BMZ Priority	Cooperation Needed
North and West Summit Mtn	432	96%	1910(36%); barren(20%); N[1](13%); hs noburn[2](9%)	Fair	1	No
Debris Creek	397	93%	N(52%); hs burn[3](23%); barren(14%); hs noburn(10%)	Good - Fair	2	No
Northwest Running Rabbit Mtn	261	96%	barren(48%); 1910(26%); X910[4](21%)	Moderate	3	Possibly
Northwest Little Dog Mtn	103	100%	N(47%); barren(32%); hs burn(8%)	Fair	4	No

[1] No recorded fire activity.
[2] Herbaceous or shrub not burned.
[3] Herbaceous or shrub burned.
[4] Before 1910.

DISCUSSION

Despite the importance of whitebark pine in subalpine forest communities, it's numbers are rapidly declining. White pine blister rust, mountain pine beetle, and fire suppression are agents responsible for this decline. Many have recommended the reintroduction of fire into whitebark pine communities as a first step in curbing this alarming trend. A detailed approach to implementing this recommendation was offered in this paper.

The locations of seral whitebark pine habitat in Glacier National Park had not been previously mapped. Furthermore, a protocol was not established that prioritized this habitat for targeting in restoration efforts. A multivariate geospatial analysis predicted the extent of seral whitebark pine habitat within the Park. Then, these areas were prioritized based on total stand aggregate area, time since last fire, probability of occurrence, and relative accessibility from trails.

Due strongly to fire history, the St. Mary, Many Glacier, and Belly River subdistricts, and the Muir and Park Bear Management Zones all possess stand aggregates of high priority overall. The first three of these areas are prioritized highest, respectively, primarily due to the amounts of potential habitat. With the exception of the Nyack BMZ, much of the Middle Fork subdistrict is moderately prioritized. The McDonald subdistrict follows in priority. Stand aggregates within these areas should receive fire management attention first. The remaining areas are prioritized low.

Table 2 suggest the over-prediction of the spatial extent of potential habitat on the east side. The reason for this over-prediction appears to involve the use of the distance from the continental divide grid in the habitat classification. The predicted extent of seral whitebark pine habitat without this grid was much less, however, accuracy diminished as well. Given spatial data regarding soils and climate to replace the use of this value grid, this over-prediction bay have been avoided and the classification more accurate. It is suggested that a habitat classification of this kind utilize as many geo-spatial data layers as possible relating to topography, soils/geology, and climate. A stepwise discriminant analysis is useful in suggesting what spatial data is most effective in separating habitat type classes. Utilizing these data is assumed to increase both accuracy and spatial resolution of habitat types, allowing for broader fire management applications.

Although the calculated fire return interval between 1978 and 1998 is derived from a relatively short time span, it strongly suggests that seral whitebark pine communities in Glacier National Park are presently exceeding fire return intervals that historically perpetuated these stands and that current fire management policy remains too conservative. The large Kootenai Complex fires in the early fall of 1998 burned over 2400 acres of potential habitat providing a good reintroduction of fire to this habitat. Prescribed natural fires, such as those of 1998, must be allowed to burn if whitebark pine habitat is to be reestablished. In addition, it is recommended that management ignited fires increase in scale, both in frequency and size, as Lansing (1999) proposed.

APPENDIX

APPENDIX A

List of wildlife species that consume whitebark pine seeds and their fire tolerance

Wildlife Species[1]	Fire Tolerance[2]
Black bear (Ursus americana)	Benefits from abundant regeneration of berry-producing shrubs following fire.
Chipmunk (Eutamias spp.)	Temporarily decrease. Usually abundant after 2nd or 3rd year post-fire. Depends on species.
Cassin's finch (Carpodacus cassinii)	Intolerant
Clark's nutcracker (Nucifraga columbiana)	Adapted
Grizzly bear (Ursus arctos horribilis)	Seral forest communities maintained by fire are important for preferred berry-producing plants.
Golden-mantled ground squirrel (Spermophilus lateralis)	Generally increases on recently burned areas due to increased abundance of forbs, providing adequate escape cover exists.
Hairy woodpecker (Picoides villosus)	Adapted
Mountain chickadee (Parsus gambeli)	Intolerant
Pine grosbeak (Pinicola enucleator)	Not Identified
Raven (Corvus spp.)	Impervious
Red-breasted nuthatch (Sitta canadensis)	Intolerant
Red crossbill (Loxia curvirostra)	Intolerant
Red squirrel (Tamiasciuris hudsonicus)	Essentially eliminated following stand-replacing fires. Cavities in fire-killed trees may be used for dens but only if surrounded by live trees.
Steller's Jay (Cyanocitta stelleri)	Impervious
White-breasted nuthatch (Sitta carolinensis)	Not Identified
White-headed woodpecker (Picoides albolarvatus)	Not Identified
Williamson's sapsucker (Sphyrapicus thyroideus)	Adapted

Other wildlife species using whitebark pine habitat and their fire tolerance

Wildlife Species[1]	Fire Tolerance[2]
Blue grouse (Dendragapus obscurus)	Dependent
Mountain bluebirds (Sialia currucoides)	Adapted
Northern flickers (Colaptes auratus)	Adapted

[1]From Kendall and Arno 1990.
[2]Adapted from Fischer and Bradley 1987.

APPENDIX B

Common Vascular Plant Species Above 5000 feet Elevation

Forbs:

Achillea millefolium (common yarrow)
Arnica cordifolia (heart-leaf arnica)
†A. latifolia (broadleaf arnica)
Castilleja rhexifolia (Rhexia-leaved paintbrush)
†Epilobium angustifolium (fireweed)
Erythronium grandiflorum (glacier-lily)
Fragaria virginiana (Virginia strawberry)
Galium boreale (Northern bedstraw)
Goodyera oblongifolia (Western rattlesnake-plant)
Heracleum lanatum (cow-parsnip)
Heuchera cylindrica (roundleaf alumroot)
Mitella breweri (Brewer’s mitrewort)
Pedicularis bracteosa (bracted lousewort)
Potentilla diversifolia (diverse-leaved cinquefoil)
Pyrola secunda (one-sided wintergreen)
Saxifraga bronchialis (spotted saxifrage)
†Sedum lanceolatum (lance-leaved stonecrop)
Senecio triangularis (arrowleaf groundsel)
†Thalictrum occidentale (Western meadowrue)
†Valeriana sitchensis (Sitka valerian)
Veratrum virde (green false hellebore)
Viola orbiculata (round-leaved violet)
†Xerophyllum tenax (beargrass)

Graminoids:

Carex geyeri (elk sedge)
Festuca idahoensis (Idaho fescue)
†Luzula hitchcockii (smooth woodrush)

Shrubs:

Acer glabrum (Rocky Mountain maple)
Alnus sinuata (Sitka alder)
Amelanchier alnifolia (Western Serviceberry)
Arctostaphylos uva-ursi (kinnikinnick)
Chimaphila umbellata var. occidentalis (common princes’s-pine)
Juniperus communis (common juniper)
Lonicera utahensis (Utah honeysuckle)
†Menziesia ferruginea var. glabella (fool’s huckleberry)

Pachistima myrsinites (mountain-lover)
Penstemon fruticosus (bush penstemon)
Potentilla fruticosa (shrubby cinquefoil)
Ribes lacustre (swamp currant)
Rubus parviflorus (thimbleberry)
Sambucus racemosa (red elderberry)
Shepherdia canadensis (Canada buffaloberry)
Sorbus scopulina (Cascade Mountain-ash)
S. sitchensis var. sitchensis (Sitka Mountain-ash)
Spiraea betulifolia var. lucida (Shiny-leaf spiraea)
[†]Vaccinium globulare (globe huckleberry)
[†]V. scoparuim (whortleberry)

Trees:
[†]Abies lasiocarpa (subalpine fir)
Larix lyallii (subalpine larch)
L. occidentalis (Western larch)
[†]Picea engelmannii (Engelmann spruce)
[†]Pinus albicaulis (whitebark pine)
P. contorta (lodgepole pine)
P. flexilis (limber pine)
Pseudotsuga menziesii var. glauca (Rocky Mountain Douglas-fir)

[†]Plant species common in seral whitebark pine communities

APPENDIX C

Diseases and Insects Affecting Whitebark Pine (Pinus albicaulis)
Adapted from Hagle et al. 1987

Aphididae – Aphid
Arceuthobium americanum – Lodgepole pine dwarf mistletoe
A. cyanocarpum – Limber pine dwarf mistletoe
A. laricis – Larch mistletoe
Armillaria ostoyae – Armillaria root rot
Atropellis piniphila – Atropellis canker
Buprestidae – Flatheaded wood borer, metallic wood borer
Cerambycidae – Roundheaded wood borer, longhorned beetle
Cronartium ribicola – White pine blister rust
Dendroctonus ponderosae – Mountain pine beetle
D. valens – Red turpentine beetle
Eocosma spp. – Cone borer
Fomes annosus – Annosus root rot
Gnathotrichus spp. – Ambrosia beetle
Herpotrichia coulteri – Snow mold
Ips pini – Pine engraver beetle
Leptoglossus occidentalis – Western conifer seed bug
Lophodermella arcuata – Lophodermella needle cast
Phaeolus schweinitzii – Schweinitzii root and butt rot
Slatypis spp. – Ambrosia beetle
Trypodendron spp. – Ambrosia beetle
Xyleborus spp. – Ambrosia beetle

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