FIRE RESTORATION OPTIONS IN LODGEPOLE PINE ECOSYSTEMS

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ABSTRACT

Ecosystem management strategies embraced by natural resource management agencies advocate increased application of prescribed fire on a landscape scale. These strategies are formulated in response to interpretations of wildland ecosystem health, both real and perceived. These strategies are also advancing from reevaluation of traditional fire exclusion policies and small-scale stand management practices to larger scale applications. Implications of past management, although most apparent in areas that have experienced frequent fire occurrence, are also evident in ecosystems that historically experienced mixed fire regimes. These effects are manifested in the form of alterations in stand age distributions, stand structure, fuel accumulation, insect and disease proliferation and intensification, and potential fire intensity, frequency, and spread rates.

Lodgepole pine (*Pinus contorta*) represents an example of an ecosystem that historically experienced what can be categorized as a mixed fire regime, i.e., infrequent high-intensity stand-replacing fires in conjunction with frequent low- to moderate-intensity surface fires. Management of lodgepole pine forests must involve consideration of fire restoration needs. These needs pose challenges having much greater complexity than those in systems where fire restoration objectives involve less risky fire applications. Prerequisite to undertaking and implementing successful restoration and management of fire in lodgepole pine is a comprehensive understanding of the role of fire in this type. Such an understanding must balance many variables including fire regimes, fire behavior, fuel dynamics, community dynamics, succession, cone serotiny, stand establishment, and insect and disease interrelationships. This paper addresses several available options for utilizing management-ignited prescribed fire and prescribed natural fire strategies for ecosystem restoration objectives in lodgepole pine communities.

Citation: Zimmerman, G. Thomas, and Philip N. Omi. 1998. Fire restoration options in lodgepole pine ecosystems. Pages 285–297 *in* Teresa L. Pruden and Leonard A. Brennan (eds.). Fire in ecosystem management: shifting the paradigm from suppression to prescription. Tall Timbers Fire Ecology Conference Proceedings, No. 20. Tall Timbers Research Station, Tallahassee, FL.

INTRODUCTION

Throughout this century, the field of fire management has evolved from an incongruous posture advocating total fire exclusion to a multidimensional approach embracing total ecosystem management with the necessary incorporation of controlled fire application and restoration of fire as a natural process. This continued growth and advancement of management capability has been driven by advances in knowledge and awareness of the natural role of fire, historical fire regimes, fuel and stand dynamics in the presence and absence of fire, and practical experience gained from widespread suppression efforts and observation of their effects.

Many forest ecosystems in the United States are experiencing an erosion of general health that has escalated far above historical conditions (Botti et al. 1994, Mutch 1994, Mutch et al. 1993). These forest health problems are most advanced in short-interval fire-adapted ecosystems, predominantly represented by long-needled pine communities (Williams et al. 1993). But, cultural activities and their interaction with ecosystem dynamics are fostering changes in mixed fire regimes as well, where frequent low- to moderate-intensity and severity surface fires historically combined with infrequent high-intensity stand-replacing fires.

Lodgepole pine communities represent variable-interval fire-adapted ecosystems where individual fire severity ranges between nonlethal surface fires and lethal stand-replacing fires. Historically, these ecosystems were characterized by a rich pattern of age classes configuring the landscape in a mixed mosaic. Widespread successful fire exclusion in combination with small-scale forest management and localized prescribed burning have resulted in severe alterations of age-class distributions. In areas where historic fire return intervals were shorter, a large-scale shift from a ubiquity of young age classes to dominance by mid-level age classes in the 100–170 year range is occurring, especially in the central and southern Rocky Mountains (Averill, personal communication, 1996). At cooler and moister locales, historic fire occurrence was probably somewhat lower. In these areas, current age class structure illustrates a trend toward greater proportions of older age class stands, strongly apparent in the eastern portions of the northern Rocky Mountains and Greater Yellowstone Area (Bollenbacher, personal communication, 1996).

Age-class modifications taken superficially may not appear unreasonable, but associated ecological al-

terations are pervasive in these communities, both directly and indirectly. Adjustments in stand structure, fuel accumulation, and rates of insect and disease proliferation and intensification are occurring and are responsible for undesirable amplifications in potential fire intensity, severity, frequency, and spread rates.

Numerous initiatives, directives, reports, and pilot programs support increased prescribed fire accomplishments in short-interval fire-adapted ecosystems (USDI/USDA 1995, Botti et al. 1994, Mutch 1994, Williams et al. 1993). However, other ecosystems must also be given close scrutiny and attention to minimize further ecological degradation. Changing stand conditions and the recent scale and expenditures of fire suppression activities in lodgepole pine forests attest to the importance and increasing urgency of evaluating fire restoration needs and opportunities here.

Prescribed fire application and restoration of wildland fire as a natural process in lodgepole pine ecosystems as a management activity will face greater complexity and associated risk than in some other ecosystems. However difficult, increasing knowledge and experience support our management capability; success in this undertaking can be achieved within acceptable risk levels. This paper presents a synopsis of available options for fire restoration in lodgepole pine ecosystems based on a review of preliminary case examples of fire applications and management. Considerations prerequisite to the application of fire restoration actions and evaluation of effectiveness are also provided.

EVALUATION OF THE ROLE OF FIRE IN RESTORATION, REHABILITATION, AND MAINTENANCE OF LODGEPOLE PINE ECOSYSTEMS

Prerequisite to successful application and reintroduction of fire in lodgepole pine communities is a complete understanding of the historic role of fire including fire regimes, fire behavior, fuel dynamics, previous management activities, community dynamics, succession, cone serotiny, stand establishment, and insect and disease interrelationships. Selection of fire as a viable treatment must be based on adequate evaluation of the ecosystem situation and potential beneficial effects of fire. Once fire is selected as a desirable management application, close attention and monitoring will be necessary to evaluate application effectiveness and refine prescriptions.

Petersburg (1992) presents a list of considerations that must be addressed prior to and during implementation of any program of fire restoration. Christensen (1995) states that management must be adaptive; any reasonable system must include an integral evaluation mechanism to assess the degree of accomplishment. We strongly support this concept and have modified Petersburg's list to better fit variable-interval fire-adapted ecosystems represented by lodgepole pine. We offer the following eight considerations that we feel are prerequisite to the process of planning and implementing fire restoration:

Historic Ecosystem Configuration (describe to the extent possible, how the ecosystem was configured prior to the interaction of cultural activities and ecosystem dynamics).

Historic Role of Fire (describe the historic fire regime, fuel dynamics, and the effects of fire presence).

Current Ecosystem Description (relate all quantifiable information regarding the current situation, especially the impacts of fire absence).

Desired Configuration or Conditions (describe the desired condition or desired natural processes).

Future Configuration without Restoration Efforts (what trend is developing, what condition will the ecosystem be in without fire restoration).

Test Treatment and Monitor/Evaluate (initiate fire restoration applications, monitor at sufficient intensity to permit evaluation of success).

Full Treatment Implementation (if treatment is successful, implement at scale necessary to accomplish desired goals and objectives).

Program Monitoring and Evaluation (if fire restoration efforts have been initiated, it is most likely due to a desire to reverse some ecological alterations. Christensen (1991) states that managers cannot disregard past treatments and allow ecological processes to occur as if no human-caused disturbance or action had occurred. He states that we are obliged to manage and we must monitor to continually assess our effectiveness.)

Addressing these considerations before and during implementation of fire restoration efforts in lodgepole pine communities will greatly contribute to long-term programmatic success.

FIRE RESTORATION OPTIONS

Fire restoration options in lodgepole pine ecosystems are based on the application of management-ignited prescribed fire (MIPF) and prescribed natural fire (PNF). Management-ignited prescribed fire is defined as those prescribed fires intentionally ignited by managers under a predetermined set of environmental and fuel conditions (prescription), controlled by an array of predefined and allocated control forces and /or conditions, and planned to burn only within a specified area within a definite timeframe. Prescribed natural fire includes those prescribed fires ignited by natural causes, almost solely confined to lightning, and managed to accomplish specified resource objectives as long as the fire remains within the capability of the managing unit, within a defined set of environmental conditions (prescription), and within a preplanned geographic area. Primary differences between these two strategies involve type of ignition, duration of burning, operational planning and written documentation, intensity

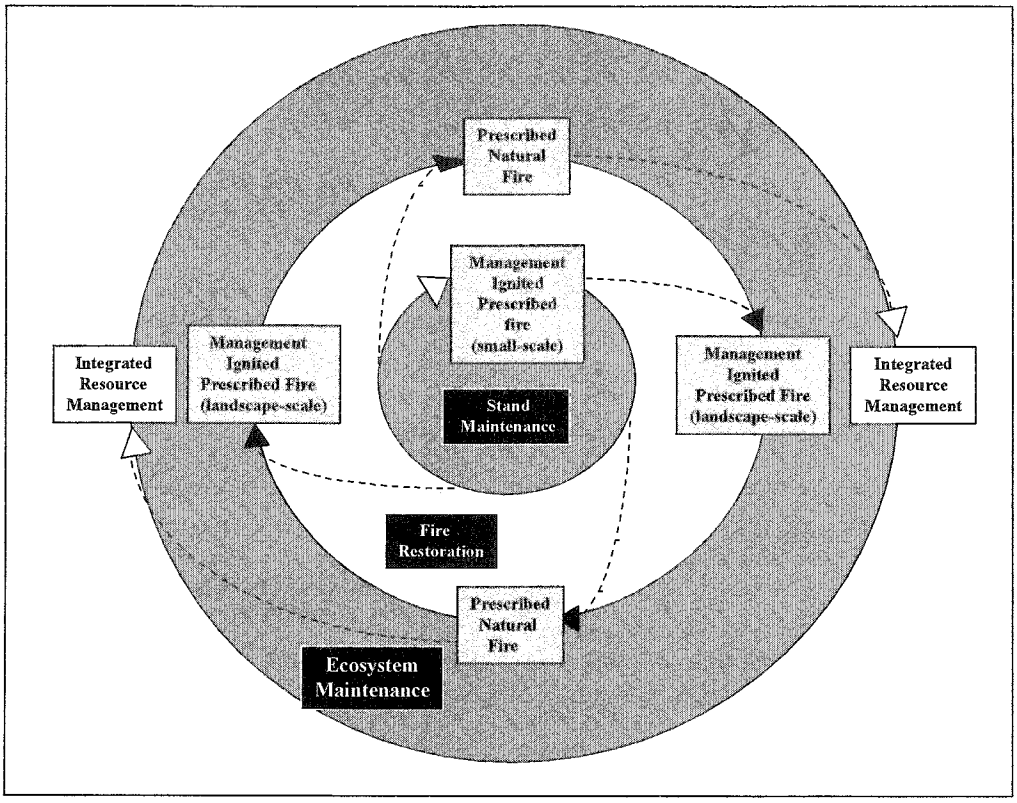

Fig. 1. Management options for restoring and maintaining fire-adapted ecosystems.

and duration of monitoring and evaluation, and internal agency considerations. A specific plan is prepared in response to an ignition for prescribed natural fires while management-ignited prescribed fires have plans prepared in advance of ignition. Uncertainty and risk are greater for prescribed natural fires than for management-ignited prescribed fires due to the extent and duration of burning in the preplanned area.

Management-ignited prescribed fire is a justifiable fire treatment in lodgepole pine communities where it can be applied under controllable conditions and can be kept consistent with prescription parameters and objectives. This prescribed fire strategy is capable of replicating natural fire effects and can be successfully managed to accomplish fire restoration goals in lodgepole pine ecosystems when management prescriptions are founded on fire history and current successional status (Brown 1993). However, the potential effectiveness of the management-ignited prescribed fire has been questioned in terms of its ability to replicate historic patterns of burn heterogeneity (Despain and Romme 1991). Historical use of this strategy has been limited to silvicultural management on a relatively small scale in the West. Objectives have largely involved site preparation in terms of reduction of fuel and competing vegetation, creation of a mineral seedbed, and facilitation of artificial regeneration techniques following mechanical removal of large volumes of overstory wood products.

A prescribed natural fire strategy offers opportunities to realize the full range of historical fire behavior and intensity and potential restoration of fire as a natural process. However, numerous limitations to widespread use of this strategy exist and will, in many cases, necessarily limit application. Issues range from fundamental resource management objectives to techniques and capability of managing long-term high-intensity fire events (White and Pengelly 1992). Conversely, the application of fire in lodgepole pine ecosystems without excluding high-intensity events must be accomplished. Spatial limitations will influence management by defining where prescribed natural fires will be allowed to fully simulate historic events or be forced into suppression status. Stephenson et al. (1991) present a case in point illustrating that there are ecological costs associated with exclusion of high-intensity fire events from certain parts of the landscape. Lodgepole pine ecosystems represent a portion of the landscape that cannot be managed without high-intensity fire events.

Management options available for restoration and maintenance primarily include prescribed fire applications, but other alternatives not limited to fire exist including mechanical and physical manipulation. Figure 1 presents general management options for restoring and maintaining fire-adapted ecosystems. This figure can best be described in terms of three spatial and management components: stand maintenance; fire restoration; and ecosystem maintenance.

The stand maintenance area (diagram center) illustrates historical management of many fire-adapted ecosystems. Past use of prescribed fire has been concentrated in hazard reduction and site preparation functions in conjunction with timber harvesting and stand

regeneration (Crane and Fischer 1986). This use of fire has been restricted to small-scale stand management and maintenance actions. At this scale, the majority of the landscape has been left untreated. Prescribed fire application at this scale represents a patch-type situation that does not replicate historic landscape disturbances such as the occurrence of large-scale stand replacement. Thus, management options here cycle directly back to themselves showing little long-term program expansion. This patch application does approximate a maintenance level of fire application by continually reducing fuel continuity, and in many cases, extending the timeframe of total stand replacement from disturbance combinations. Some lodgepole pine stands withstand repeated low-intensity burns that produce moderate-density, high-volume stands eventually converted by fire after a relatively long fire-free interval.

The fire restoration area (Figure 1, middle ring) represents escalation of a fire management program to include appropriate fire restoration activities. Management-ignited prescribed fire, conducted on a landscape-scale, and prescribed natural fire can successfully advance fire restoration. Management-ignited prescribed fire on a small-scale can be used to prepare and facilitate implementation of both prescribed natural fire and landscape-scale management-ignited prescribed fire. These two activities can function individually or in combination to promote mutual successes. Once a program has escalated to this level, fire restoration will begin to mimic historic ecosystem processes and reduce risks from future applications.

The ecosystem maintenance area (Figure 1, outer ring) represents a program of ecosystem conversion and maintenance resulting from large-scale fire restoration. Successful application of prescribed natural fire and landscape-scale management-ignited prescribed fire can solidify full implementation of a fully integrated fire and resource management program. Such a program achieves a necessary balance of all aspects of fire management, including fire exclusion and use. Ecosystem maintenance can be attained with replication of historic processes of age-class mosaic establishment and maintenance, regulation of fuel accretion rates, reestablishment and maintenance of cone serotiny, dynamic successional trends, regulation of insect and disease populations, and maintenance of biological diversity. Integrated management of fire as a natural process is fundamental to this concept. Management actions continue to include prompt suppression of unwanted fires coupled with timely applications of prescribed fire options and may include other nonfire management strategies.

Not all areas are suitable for full implementation of a fire restoration program culminating in balanced fire and resource management. Some areas will be limited to application of landscape-scale management-ignited prescribed fire and all areas will require continued small-scale stand maintenance and stand conversion prescribed burning. Assessment of risk must accompany all potential evaluations for fire restoration. However, risk taking initially can yield long-term benefits. As fire management programs expand from the smallest scope of stand maintenance, risk associated with fire applications will decrease with increased prescribed fire activity reducing extensive fuel associations and expediting control capability.

FIRE RESTORATION CASE EXAMPLES

Two case examples of prescribed fire application in lodgepole pine ecosystems are presented in the following section. The first example illustrates how small-scale management-ignited prescribed fire can be used to enhance opportunities for landscape-scale prescribed fire applications. The second example describes a sequence of prescribed fire applications including both small-scale and landscape-scale management-ignited prescribed fire and prescribed natural fire. Efforts to date in these examples have been limited but completed examples and ongoing efforts are described. All examples are presented through association to the eight considerations previously discussed.

Management-Ignited Prescribed Fire (small-scale and landscape-scale)—Gunnison National Forest, Colorado

Nearly 15 years ago, efforts were made in southwestern Colorado on the Gunnison National Forest to evaluate the effectiveness of prescribed fire for controlling dwarf mistletoe (*Arceuthobium americanum*) in lodgepole pine stands. Objectives of this project were to cause 75–100% host tree mortality through the application of prescribed fire that simulated wildfire intensity and severity and initiated lodgepole regeneration.

Following initial successes, burning efforts have greatly expanded. Ongoing program objectives include disease control, wildlife habitat improvement, range improvement, maintenance of biological diversity, establishment and maintenance of historically replicated age-class mosaics, and restoration of fire to the maximum extent possible (Chonka, personal communication, 1996). During the intervening 15 years since the first prescribed fire was ignited, a combination of mechanical vegetation manipulation treatments (roller-chopping, dozer brush-blading, slash piling), piled slash burning, timber harvesting, small-scale management-ignited prescribed fire, and landscape-scale management-ignited prescribed fire have been integrated into a resource management program that accomplishes ecosystem maintenance and fire restoration.

Historic Ecosystem Configuration

Historically, forest communities were distributed along elevational gradients with ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*) occupying lower areas. Lodgepole pine was common in transitional areas between pine and Douglas-fir and higher elevation spruce-fir forests. Occasionally, cold, dry pockets permitted lodgepole pine to occupy high elevation valley bottoms and range almost to timberlines. Spruce-fir forests occupied those areas adjacent to timberlines and along high elevation water courses.

Lodgepole pine forests experienced a mixed fire regime as attested by abundant fire scars. Age-class mosaics were prominent with the largest proportion of stands representing very young ages. The advent of gold mining brought human settlement and considerable forest clearing in the late 1800's.

Historic Role of Fire

Wildland fire was a moderately frequent visitor to this ecosystem. It occurred with varying intensity and severity at periodic intervals. Specific effects were generated from each intensity level and replicated over time.

Fire scar analysis provides insight into that nonlethal portion of fire history while stand age analysis can infer approximate occurrence of high intensity and severity stand-replacing fire events. Prior to 1860, the following range of fire frequencies existed: ponderosa pine, 12–20 years; Douglas-fir, 20–35 years; low elevation lodgepole pine with bitterbrush understory, 30–50 years; lodgepole pine surface fire, 70–90 years; lodgepole pine stand replacement, 170–220 years; spruce-fir, 280–400 years; and aspen stand replacement fires, 120–250 years (Chonka, personal communication, 1996). The most active period of fire occurrence in the area as indicated from fire scar analyses was between 1858 and 1882. Numbers of fires occurring before the peak were much lower. A decline in fire occurrence, as indicated by scarred trees, occurred during the last 110 years.

Current Ecosystem Description

The area involved in this project is situated in southwestern Colorado, between the towns of Gunnison and Aspen. Vegetation includes an array of elevationally distributed communities including: sagebrush (*Artemesia* spp.), ponderosa pine, Douglas-fir, aspen (*Populus* spp.), lodgepole pine, spruce-fir, and alpine tundra. Fire exclusion has promoted mixing of some of these vegetation types, most notably: Douglas-fir and lodgepole pine regeneration dominated by ponderosa pine overstories; and lodgepole pine under Douglas-fir canopies. Continuous lodgepole pine stands are heavily infected with dwarf mistletoe. In fact, parasite populations have intensified to the point where >50% of all lodgepole pine stands in Colorado (USDA Forest Service 1995a) and in some areas of the Gunnison NF, >75% of all stands are infected (Zimmerman and Laven 1984).

Stand age analysis of lodgepole pine stands shows that the majority of stands are in the mid-age range, between 100 and 140 years. Stands representing young and overmature age classes are noticeably lacking.

Desired Configuration or Conditions

The desired configuration for this ecosystem is a functioning system influenced by fire that limits species mixing, establishes historic age-class distributions, replicates natural fire regulation of dwarf mistletoe, reduces natural fuels to prefire exclusion levels, and maintains biological diversity. Reestablishment of a natural or management-ignited fire regime of periodic low- to moderate-intensity surface fires with infrequent high-intensity stand-replacement fires is necessary to achieve this configuration.

Future Configuration without Restoration Efforts

Efforts to exclude fire from these communities have been highly successful with exception of major episodes. Successful fire exclusion has removed the only natural control of dwarf mistletoe, promoted increases in fuel accumulations, and diminished biological diversity. Without restoration of fire, this ecosystem can be predicted to develop in the following ways.

In the absence of natural fires, prescribed fires, or alternative dwarf mistletoe control or reduction methods, continued parasite spread and intensification will occur, which will drastically reduce stand productivity, alter stand structure, cause early mortality, increase downed and aerial fuel loading, and cause changes in potential fire intensity. An altered fire regime could result in which moderate- to high-intensity surface fires will quickly become high-intensity surface fires and passive crown fires.

A mosaic of few age classes could reach a stage of high potential fire intensity synchronously which, in combination with the altered fire regime, will create conditions of extreme fire intensity potential and pose considerable problems for managers. This, in combination with increased fuel loading, could drastically affect forest protection capabilities.

If wildfires have favored cone serotiny, then fire exclusion should serve to diminish cone serotiny. If stand age distributions favor simultaneous burning of many stands, lodgepole pine may be dramatically reduced or even eliminated from the area due to loss of a seed source. Loss of intra- and inter-stand diversity will significantly affect carrying capacity for wildlife species.

Test Treatment and Monitor-Evaluate

Prescribed burning was carried out under conditions commonly experienced during both summer and fall seasons in five test units. Four units were burned during September and October while one was burned during late June. All burns were completed under conditions of low to moderate winds from favorable directions. Dead fuel moisture contents in the smallest category ranged from 4–6%, while in the next larger category (1/4 to 1 inch) (0.64 to 2.54 centimeters), contents ranged from 7–9%. Observed duff layer moisture contents were markedly low during all burning.

Stand 1 burned with a combination of heading and backing surface fires and passive and active crown fires. Stand 5 was the first unit to be burned during the fall. This stand burned with variable fire intensities and fire types including heading and backing surface fires, and passive, active, and independent crown fires. Stand 2 was ignited by strip head fires during midmorning hours and produced heading and backing sur-

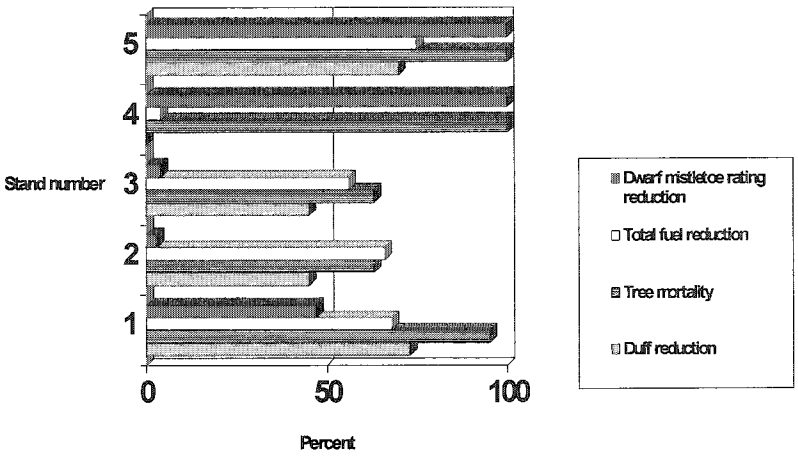

Fig. 2. Fire effects on lodgepole pine stand characteristics—small-scale management-ignited prescribed burns, Gunnison National Forest, Colorado.

face fires and occasional passive crown fires. The surface fires ranged in intensity from low (in fact, many places did not even burn) to moderate. Stand 3 possessed substantial quantities of dead fuel and tree regeneration in addition to the overstory. Type of fires occurring here included heading and backing surface fires and passive crown fires. Stand 4 was burned by a combination of surface head fires and active crown fire.

Zimmerman et al. (1990) provide a complete description of preburn conditions, prescribed burning observations, and direct effects of these fires. Figure 2 summarizes the full range of effects observed on these site-specific prescribed fires.

Full Treatment Implementation

Following initial dwarf mistletoe control prescribed burns, it was determined that high-intensity prescribed burns could be applied to the lodgepole pine ecosystem successfully. As a result, the Taylor Canyon project was started for the purpose of improving bighorn sheep habitat on summer and winter ranges and to restore and maintain a 20 mile (33 kilometers) corridor between the two ranges. Early efforts consisted of small-scale, site-specific burn units with numerous prescribed fire plans prepared. Project objectives have grown as knowledge and experience have increased and current objectives strive to apply fire to mimic historic patterns and intensities.

Management-ignited prescribed fire is applied primarily through hand ignition utilizing strip head firing patterns. Area ignition is frequently utilized in dense lodgepole pine stands having heavy downed fuel loads. This ignition technique can promote intensities high enough to maximize tree mortality and facilitate active spread through spotting and actively moving high-intensity surface fires. Active crown fires occur when vertical fuel continuity promotes vertical fire spread. Independent crown fires develop in situations where canopy closure is greater than 70–80% and steep slopes (>30%) or winds in excess of 6–8 mph (10–14 kph) are present. Two plume-dominated events have been observed following area ignition on sites with slopes less than 10%, light winds (<4 mph) (6.7 kph), and fuels dominated by heavy downed accumulations and overstories heavily infected by dwarf mistletoe.

Smoke dispersal, human activity, and fire weather watches influence prescription parameters. On ignition days, probability of ignition must range between 30–70% and spotting distance can range up to 0.4 miles (0.67 kilometers). Tactical operations are based on establishment of anchor points prior to ignition. Starting points consist of natural barriers or snow combined with burning for added strength. Generally, fire is brought downslope and into the wind. Preparation of areas can be time-consuming and labor-intensive, depending upon the site conditions. One area took an entire season to develop the appropriate anchor. After two seasons, two sides of a proposed burn unit were blackened for a depth of 2–2.5 miles (3.3–4.0 kilometers), sufficient to hold all but the severest of outcomes.

Early firing efforts were completed by crews of 10–15 individuals. Experience now dictates that no more than three people are necessary on a firing crew and one crew per burn unit, each equipped with a radio and supervised by an Ignition Specialist of the highest level qualification. Aerial ignition is also successful but generates costs almost twice the rate for hand ignition, $35–40/acre ($77–88/hectare) compared to $18–26/acre ($40–57/hectare). It is felt that hand firing gives better results, more complete consumption, and reduces monitoring costs over time.

Annual acreage burned varies with sites and weather, but fire is successfully applied to several thousand acres each year. No holding forces are deployed during any firing operations. Post-ignition monitoring of continued burning is completed by several individuals. Personnel with qualifications ranging from Crew Boss to Fire Behavior Analyst are utilized as monitors. Necessary qualification levels are based on National Fire Danger Rating System indices derived from observations at the closest fire weather station.

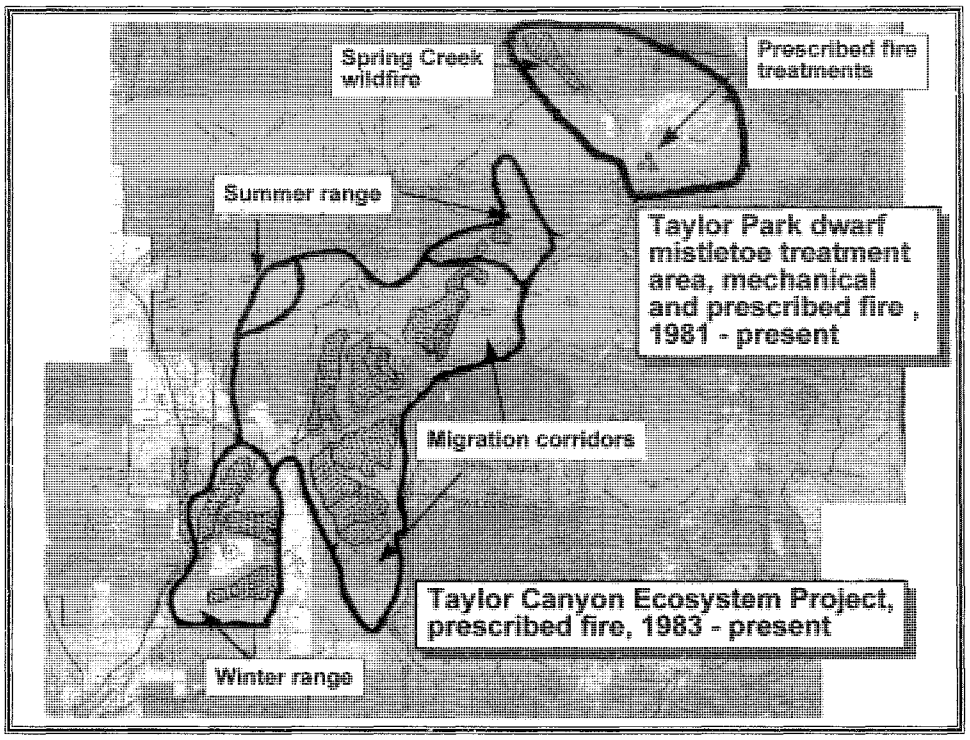

Fig. 3. Spatial extent of prescribed fire applications, wildfire burned mosaic, and mechanical and physical vegetation treatments in the Taylor Canyon Project, Gunnison National Forest, Colorado.

Evaluate Program to Monitor Degree of Accomplishment

To initiate this program, five management-ignited prescribed fires demonstrating the full range of fire behavior were carried out on a site-specific scale. As the program evolved, burn projects grew, both in numbers and scale. Over the last 15 years, 22 management-ignited prescribed fires have been completed on a landscape-scale. Several dozen stands have also been mechanically treated for disease control. All treatments, fire and nonfire, were planned to maximize the value of a significant wildfire burned area in the northern portion of the project area. Figure 3 illustrates the spatial extent of prescribed fire applications and mechanical and physical vegetation treatments involved in the project. The affected area varies from about 8000 feet (2130 meters) to over 10,000 feet (2740 meters) in elevation, covers nearly 200 square miles (560 square kilometers), and ranges from the valleys of the Gunnison Basin to the headwaters of the Gunnison River near the Continental Divide.

Success can be measured in both on-the-ground accomplishments and dramatic increases in knowledge and experience of management capability in variable-interval fire-adapted ecosystems. Although much remains to be learned about this mixed fire regime, this project as a whole can be categorized as highly successful.

As this program has grown from a small-scale site-specific application to a complete ecosystem management project, operational costs have decreased from over $300/acre ($660/hectare) to less than $30/acre ($66/hectare). Management-ignited prescribed fire is successfully applied to achieve multiple objectives including regulation of dwarf mistletoe intensification and proliferation, landscape-scale fire restoration, and maximization of biological diversity. Large-scale prescribed burn plans have been prepared and now only three plans are utilized: one for winter range; one for summer range; and one for migration routes. These three plans encompass over 53,000 acres (116,600 hectares), 14,000 acres of which have been prescribed burned to date.

This project fully exemplifies the process of program expansion shown in Figure 1. In an area where historic fire occurrence played a major role in ecosystem structure and dynamics, fire exclusion interrupted this process and was responsible for effects equal in magnitude, although drastically different. Small-scale stand management prescribed fire application was insufficient in area and frequency to replicate the historic fire process. Program expansion to include landscape-scale management-ignited prescribed fire was initiated to restore fire to the ecosystem. Continued application of both small-scale and landscape-scale management-ignited prescribed fire for more than a decade has elevated this program to the level of ecosystem maintenance. It has been observed that heterogeneity of fire severity can be achieved through management-ignited prescribed fire application. Duration of burning, season of burning, and spatial extent of affected areas directly influence the degree of heterogeneity achieved.

Another aspect of program expansion from stand maintenance to ecosystem maintenance involves two or more burns on the same site within short timeframes. Field observation in the Taylor River area in-

dicates that two or even three fire events occurred on many sites within 10–30 years of each other. The wide variation in surface fuel loading in existence today is primarily attributable to this reburn situation. Surface fuel loading accumulates rapidly following fire and in many cases, exceeds preburn levels. Postfire observation of burns conducted since 1982 show that in addition to fire-caused mortality, *Ips* beetles are responsible for elevated mortality rates in trees weakened by stem char and crown scorch. Accelerated fuel accumulation can combine with tree regeneration to present highly flammable situations. Naturally ignited reburning is a strong likelihood under these conditions.

Ecosystem maintenance and fire restoration efforts will continue in this area. Future operations will incorporate repeat application of prescribed fire to replicate double or triple burn scenarios. In addition, the close proximity of wilderness areas offers opportunities for continued program growth and possible inclusion of prescribed natural fire.

Prescribed Natural Fire and Management-Ignited Prescribed Fire (small-scale and landscape-scale)—Glacier National Park, Montana

National Park Service Wildland Fire Management Guidelines state that one of the principal objectives of wildland fire management is to perpetuate, restore, replace, or replicate natural processes to the greatest extent possible. Glacier National Park in northwestern Montana has been managing wildland fires for the majority of the twentieth century. Early fire management efforts were limited to aggressive control strategies only. During the last 30 years, this one-dimensional approach to fire and resource management has evolved into a more integrated approach that includes both small-scale and landscape-scale management-ignited prescribed fire, prescribed natural fire, and fire suppression. Efforts to restore fire have intensified within the last decade and considerable progress has been made.

Historic Ecosystem Configuration

The original vegetation of the western portion of Glacier National Park was dominated by large areas of forest communities on ridges and high elevations. Lower areas supported forests intermixed with numerous meadows and openings comprised primarily of herbaceous species along with sagebrush. In fact, many of these meadows were viewed as potential homesteading sites. Some supported hotels and stage stops along roads to Canada.

Higher elevation areas supported extensive forests comprised of western larch, Douglas-fir, and lodgepole pine. In many areas below 5000 feet (1376 meters) in elevation, pure lodgepole pine stands were common. Ponderosa pine, western larch (*Larix occidentalis*), Douglas-fir, aspen, and Engelmann spruce (*Picea engelmannii*) were also present to varying degrees. Ponderosa pine trees were usually overstory dominants, over 200 years in age and found principally on dry benchlands. This species did range onto lower ridges in association with western larch and Douglas-fir and dense shrub understories. This population is relatively unique as it represents an isolated extension of the traditional range of ponderosa pine (Habeck 1970). Meadows are representative samples of extensions of Palouse Prairie grasslands and are also somewhat unique in Glacier National Park (Koterba and Habeck 1971).

Historic Role of Fire

Fire has been a significantly influential ecological factor in determining the present composition and distribution of plant communities throughout the park. Current stand structure and composition reflect burn and reburn patterns of differential intensity and severity. Uniform age stands represent past stand-replacement fires while fire-scarred trees bear witness to past nonlethal surface fires. The patchy, more limited distribution of older stands indicates long-term fire-free intervals, possibly in excess of 200 years.

A fire history study completed by Barrett (1983) in western Glacier National Park documents nearly 300 years of fire activity. He identified 55 fire years between 1655 and 1926, when organized fire exclusion efforts began in earnest in the park. The general pattern of fire occurrence shows frequent and often extensive underburning followed by occasional stand-replacing fires.

Fire frequency and severity have not been evenly distributed over time. Between 1655 and the early 1800's, there were few large, stand-destroying fires. After this period, large-scale stand-replacement fires returned and replaced about 32% of the North Fork's forests and partially replaced about 10%. Current stands of lodgepole pine and larch date from fires in the 1800's and early 1900's. Average fire intervals vary but include occurrence of large fires of 1000–10,000 acres (455–4550 hectares) about every 16–23 years and major fires larger than 10,000 acres (4550 hectares) every 39 years (Barrett 1983).

Since the 1930's, two major fires have occurred in this area, even with the advent of organized fire suppression. In 1967, 6300 acres were burned while in 1988, 27,500 acres (12,500 hectares) were burned in the Red Bench fire. The Red Bench fire consumed about 60% of forested communities within its boundaries in crown fires.

Current Ecosystem Description

Forest composition, principally unaltered by fire exclusion to this point in time, is representative of what has been described above in the Historic Ecosystem Configuration section. However, many stands have not experienced fire for nearly the maximum historical fire-free period. Fuel buildups, although not yet excessively large, are increasing and isolated areas of dramatic escalation can be found. A significant mountain pine beetle infestation during the 1970's and 1980's was responsible for mortality of more than 50% of the mature lodgepole pine component in this area and is promoting accelerated fuel accretion. Mountain pine beetle populations have currently dropped to the

lowest levels recorded in Montana for the past 25 years (USDA Forest Service 1995b).

Fire suppression policies adopted by the National Park Service that provided for aggressive fire suppression and fire exclusion are directly responsible for the current condition of meadows. Lodgepole pine stands now are actively encroaching into these meadow areas and historic scenes are rapidly changing to a more forested situation. Historically, large fires burned into the park from what are now private holdings and part of the Flathead National Forest. Due to developments on the private holdings, fires starting along the west side of the North Fork of the Flathead River are fully suppressed. This scenario effectively eliminates a major source of fire from the current ecosystem. Only the Red Bench Fire of 1988 has entered from outside the park since the 1930's.

Desired Configuration or Conditions

The desired configuration will be to have low elevation meadow conditions restored and maintained by removing encroaching lodgepole pine trees and reintroducing fire into higher elevation stands. The Glacier National Park Fire Management Plan specifically calls for the restoration of fire to its natural role and restoration of historic scenes where possible.

Since the current ecosystem configuration tends to still mimic the historic situation, the desired configuration exists in much of the area. Functioning of natural process, however, is not continuing at historic levels. Fire restoration efforts are designed to reestablish and maintain historic ecosystem processes.

Future Configuration without Restoration Efforts

Future configurations without fire restoration will ultimately lead to a forested site with no meadow remnants at lower elevations. Unique Palouse Prairie vegetation could be lost from the park environment. Higher elevation areas will lose age-class distributions normally maintained by periodic fire, the ponderosa pine population could also disappear from the park, and conditions for recurring large-scale insect epidemics could recur. Postepidemic fuel dynamics could favor large-scale high-intensity and severity fires that could adversely affect ecosystem components and alter future configurations.

Test Treatment and Monitor-Evaluate

Management-ignited prescribed fires were initiated in 1983 and resumed in 1992. Fires were successfully managed in nearly the full spectrum of fire types (low- to high-intensity surface fires, passive and active crown fires). The 1983 Logging Prescribed Fire has been described by Wakimoto (1984) and Kilgore (1986). This fire and later prescribed fires demonstrated that management-ignited prescribed fire could be applied to lodgepole pine sites on a small-scale and achieve desired objectives. Management-ignited prescribed fires applied on a much larger scale have not yet been carried out but proposals have been developed and planning is ongoing.

Prescribed natural fire was operational in the park prior to 1988 but seemingly did not play a major role due to spatial designations and acceptable prescriptions. Little experience was gained from the pre-1988 prescribed natural fire program.

Full Treatment Implementation

Following the 1988 fire season, all National Park Service units prepared new Fire Management Plans. Approval of these plans was prerequisite to reimplementation of natural fire programs. Glacier National Park's fire plan was completed, approved, and implemented in 1991.

All wildfires occurring in the park since 1988 (including the Red Bench fire) have had the appropriate suppression response taken to ensure protection of life and property, maximum firefighter safety, and efficient fiscal management. From 1989 to 1991, in the absence of a new fire management plan, wildland fire management was limited to suppression strategies only. Choosing the appropriate suppression strategy rather than automatically defaulting to the most aggressive posture has created opportunities for postfire management actions that would have otherwise not existed. Table 1 presents a summary of major wildland fire management actions in support of protection and ecosystem restoration and maintenance in the park from 1967 to 1995, and includes proposals to 1999. Data in this table clearly illustrate the expansion of Glacier National Park's fire management program from a one-dimensional, suppression-only approach to a substantially integrated application of multiple wildland fire management strategies.

Knowledge gained from the initial site-specific management-ignited prescribed burns at Logging Creek and Round and Big Prairies has provided the foundation for development of landscape-scale management-ignited prescribed fire application proposals. In addition, information from these past projects in combination with fire history and short- and long-term fire effects observations have provided the basis for formulation of the prescribed natural fire strategy and its implementation.

After 1991, the park staff managed numerous prescribed natural fires although until 1994 none demonstrated the potential to burn for extended durations or to affect large areas. In 1994, the Howling fire occurred which severely tested the park's natural fire strategy and management capability (Vanhorn and Kurth 1997). Management of this fire under the prescribed natural fire strategy permitted continued burning for 138 days. It grew to 2238 acres (1015 hectares) in size and replicated the historic fire behavior scenario described by Barrett (1983). It burned primarily in surface fuels as an understory fire. The ultimate acceptable size or spatial limitations of this fire defined as Maximum Manageable Area (MMA), was set at nearly 75,000 acres (34,090 hectares). Critically important to this limitation was the presence of the Red Bench fire

Table 1. Wildland fire management actions in support of protection and ecosystem restoration and maintenance objectives—Glacier National Park, 1967–1995 (one acre equals 0.45 hectares).

Year	Incident name	Management strategy	Area burned (acres)
1967	Huckleberry fire	Suppression—control	6300
1968–1987	Numerous fires (130)	Suppression—control	222
1983	Logging fire	Prescribed fire—management ignited	80
1984	Coal Creek fire	Suppression—containment	3000
1988	Red Bench fire	Suppression—control, containment	27500
1989–1991	Numerous fires (18)	Suppression—control	121
1992	Starvation fire	Suppression—control	125
1992	Round Prairie fire	Prescribed fire—management ignited	60
1992	Big Prairie fire	Prescribed fire—management ignited	22
1992	Numerous fires (8)	Suppression—control, containment, confinement	22
1993	Big Prairie fire #2	Prescribed fire—management ignited	16
1993	Big Prairie fire #5	Prescribed fire—management ignited	70
1994	Howling fire	Prescribed fire—natural	2238
1994	Starvation Creek fire	Suppression—control, containment (control and containment strategies utilized on Canadian portions).	3954 (3086 additional acres in Canada)
1994	Adair 2 fire	Suppression—containment, confinement	8055
1994	Anaconda fire	Suppression—confinement	400
1994	Numerous fires (16)	Suppression—control, containment, confinement	6
1995	Numerous fires (9)	Suppression—control, containment, confinement	1
1991–1995	Numerous fires (11)	Prescribed fire—natural	13
1996–1999	Anaconda—Dutch Creek fires (*proposed*)	Prescribed fire—management ignited, landscape-scale	16000 43000
1996–1999	Kishenehn Creek fires (*proposed*)	Prescribed fire—management ignited	71
1996–1999	Sage Creek fires (*proposed*)	Prescribed fire—management ignited	484
1996–1999	Sullivan Meadow fires (*proposed*)	Prescribed fire—management ignited	623

burned area along the north portion of this MMA. The Continental Divide to the east and the North Fork of the Flathead River to the west formed other significant barriers constraining spread. Two additional fires, managed as containment and confinement suppression actions, burned within the Howling fire MMA on Adair Ridge. These fires exhibited differential fire behavior dominated by varying levels of intensity of understory burning with the occurrence of several isolated crowning fire runs. These fires eventually burned together with the Howling fire for a combined total area of over 11,000 acres (5000 hectares). This burned area effectively transformed Adair Ridge into a buffer that will limit potential intensity and spread rates of future fires in this area. The existence of this burned area will also reduce the probability of undesirable outcomes from future wildland fires.

The Starvation Creek fire to the north, another large wildfire that occurred in 1994, has also created a highly effective barrier to fire spread in the PNF area. During the management of this fire, multiple strategies were utilized to accomplish the protection objective. A control strategy was applied to the western and northern portions of the perimeter. The western flank was successfully secured but along the northern front, the fire crossed into Canada and was handled under control and containment strategies by forces from that country. Once the southern perimeter was anchored into Kintla Creek, suppression forces were withdrawn to minimize firefighter exposure and control suppression expenditures. The eastern flank was then managed under a contain strategy utilizing the natural barriers of Kintla Creek, Kintla Lake, and the Continental Divide. A management-ignited prescribed fire proposal has been proposed to treat an area west from the burn area along the Canadian border to Kishenehn Creek. Completion of this burn will significantly increase the capability to protect the international border and offer greater flexibility in managing wildland fires in the area to the south.

Without the opportunity afforded by having wildfire burned areas in close proximity to the PNF management area, management of the Howling fire would have involved much greater risk. Experience gained from the 1994 fire season, and the Howling fire in particular, has proved invaluable in recent prescribed natural fire programmatic modifications and improvements (Zimmerman et al. 1995).

Continuing efforts to restore fire to this area involve further use of the current mosaic of wildfire and prescribed fire burned areas. A landscape-scale management-ignited prescribed fire is proposed for an area between Adair Ridge (location of three of the 1994 fires) and Lake MacDonald and the developments at Apgar, Glacier National Park Visitor Center, Park Headquarters, and the town of West Glacier. Completion of this project will substantially advance fire restoration efforts and greatly reduce risk associated with all future ecosystem maintenance efforts involving fire in the western portion of Glacier National Park. Figure 4 shows the mosaic of natural fire and management-ignited prescribed fire applications, wildfire burned areas, and proposed treatments through 1999 interspersed throughout an area of >300 square miles (840 square kilometers). Ecosystem restoration and maintenance efforts will continue to escalate and wildland fire management and application will play a significant role.

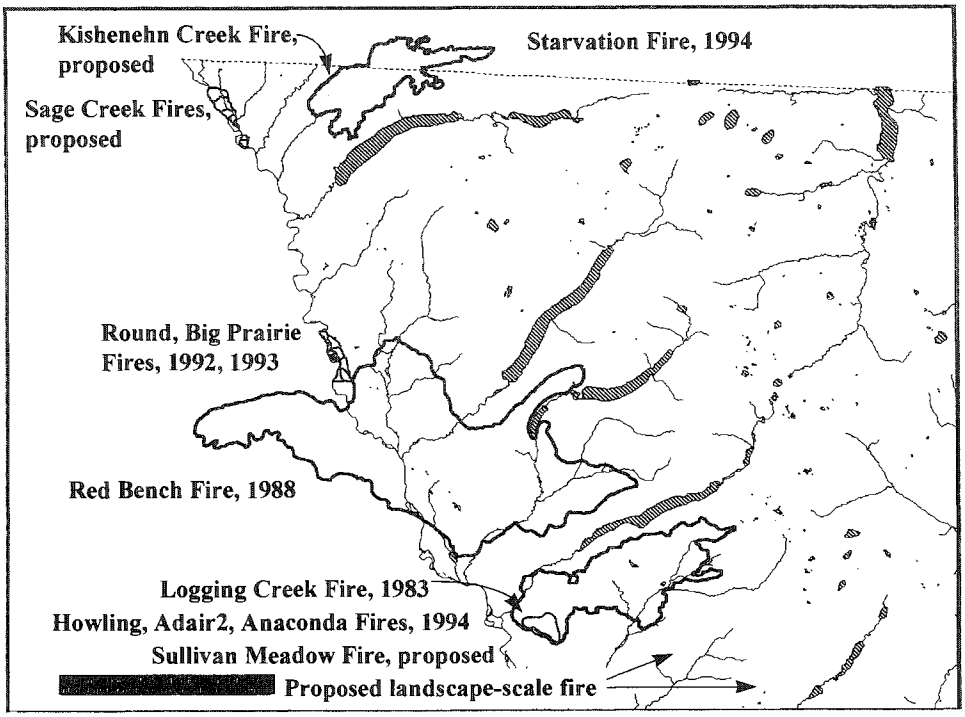

Fig. 4. Mosaic of prescribed natural fire, management-ignited prescribed fire, wildfire burned areas, and proposed prescribed fire applications through 1999 for Glacier National Park, Montana.

Evaluate Program to Monitor Degree of Accomplishment

Evaluation of this program reveals that the diversity of strategies and operational options exercised during management of wildland fires in Glacier National Park is markedly increasing. More intensive, adaptive, and creative management as well as relatively high-risk decision-making are responsible for yielding the observed results. Application of management-ignited prescribed fires of all scales and successful implementation of complex prescribed natural fires have grown steadily since 1983. In addition, wildfires in variable-interval, fire-adapted ecosystems must be viewed as ecologically significant events. Subsequent fire behavior during infrequent large-scale high-intensity fires can very quickly exceed initial action capabilities and limit suppression efforts.

Large wildfires in lodgepole pine ecosystems, while having immediate and short-term adverse impacts must be considered in terms of potential long-term opportunities to support integrated resource management. Burned areas adjacent to proposed prescribed fire applications, prescribed natural fire zones, or in close proximity to developed areas afford immense opportunities to management.

Success can be measured both by the increase of fire on the landscape and by the impact of experience and knowledge gained in wildland fire management decision-making. Accomplishments clearly follow the model of fire restoration and ecosystem maintenance illustrated in Figure 1. The Glacier National Park program is actively incorporating small-scale stand management, landscape-scale management-ignited prescribed fire, prescribed natural fire, and capitalizing on post-wildfire management opportunities to achieve an integrated resource management level of ecosystem restoration and maintenance. The diversity of efforts to date and program expansion (Table 1, Figure 4) must be viewed as highly successful.

SUMMARY

Fire restoration and ecosystem maintenance in lodgepole pine ecosystems represent a highly complex proposition, but one that can be successfully accomplished if multidimensional and multiscale management options are applied. Management-ignited prescribed fire and prescribed natural fire afford managers opportunities to apply fire for beneficial purposes. If planned operations are carefully designed and founded upon sound investigation of past fire history, current successional status, and established resource objectives, fire restoration can be accomplished. Developing management strategies that take full advantage of wildfire burned areas provide further opportunities for improving capabilities to accomplish both protection and resource management objectives. More importantly, however, is the value wildfire burned areas offer in terms of risk reduction and increasing probabilities of successful decision outcomes.

High-intensity fires must be included as an integral part of the array of prescribed fire strategic options. This type of fire, perhaps even unavoidable, poses considerable risk to result in undesirable and unpredicted outcomes (Despain and Romme 1991). But, it should be remembered that any time prescribed fire is applied

in forest ecosystems, there is risk involved (Benedict et al. 1991, Kilgore 1991, White 1990). All factors that reduce this risk and lessen the likelihood of unpredicted occurrences are highly desirable to managers. Effective vegetation manipulation, such as fire restoration, is extremely valuable in risk reduction and mitigation of potential threats to high-value resources developed in or adjacent to long-return interval ecosystems (Bunnell 1997).

Not all sites in lodgepole pine ecosystems will be suitable for fire restoration actions. Those areas significantly altered by development, under intensive management, or subject to high visitor impacts are not viable candidates for this type of management. However, those areas that fit suitability requirements warrant attention to fire restoration criteria and options. Where possible, fire restoration activities must be considered and implemented. In all fire-adapted ecosystems, risks are associated with fire use, but serious risks are associated with excluding it (Williams 1995).

Incorporation of stand maintenance and fire restoration actions will lead to successful integrated fire and resource management programs that accomplish ecosystem maintenance. Examples of successful fire restoration exist and others indicate a high probability of success. Increasing knowledge and experience support management capability to accomplish these activities.

ACKNOWLEDGMENTS

Authors wish to acknowledge the assistance and input of Jerry Chonka, U.S. Forest Service, Gunnison National Forest, and Fred Vanhorn, National Park Service, Glacier National Park, regarding management-ignited prescribed fire opportunities, accomplishments, and providing critical review; the support of Gladys Crabtree and Sheila Williams, National Park Service, and Andrea Olson, Fish and Wildlife Service, National Interagency Fire Center, for their assistance in developing figures and presentation graphics; the cooperation of Laurie Kurth, National Park Service, Zion National Park, for synthesizing information on case studies and providing critical review of this paper; the input of Steve Petersburg, National Park Service, Dinosaur National Monument, for information on considerations of fire restoration and providing critical review; and the input and review provided by Dave Bunnell, U.S. Forest Service, National Interagency Fire Center. Acknowledgment is also due to Carl Key, National Biological Service, Glacier Field Station, for his time and efforts to compile geographic information system images of Glacier National Park and its fire history.

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