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ROLE OF FIRE IN LODGEPOLE PINE FORESTS

James E. Lotan, James K. Brown, and Leon F. Neuenschwander

ABSTRACT

Fire is one of the most important factors involved in the establishment and development of many lodgepole pine forests in North America. In the Rocky Mountains lodgepole pine is usually considered a fire-maintained seral type. But even here fires vary greatly in frequency, intensity, size, and other characteristics. A particular fire regime greatly affects forest succession; longevity of the species, stocking, and species composition; and fire also influences the incidence of insects and diseases. Fuel quantity changes over time and with it fire behavior potentials in natural and slash fuels. Fire behavior potentials are greatest when buildup of dead fuel coincides with development of understory conifers. Most fires are low intensity, creeping, surface fires, but high intensity crown fires during severe weather burn the most acreage. Fires, stand development, mortality influences, and fuel accumulation interact in a complex network. Sound management of lodgepole pine requires that we understand the complexities of lodgepole pine ecology, including the role of fire, and manage fire within that context.

INTRODUCTION

Most lodgepole pine (Pinus contorta) forests were established as a result of fire, particularly in the Rocky Mountains. The role of fire in lodgepole pine ecosystems was recognized by ecologists in the early 1900s (e.g. Clements, 1910; Mason, 1915). Lodgepole pine is abundant in much of western North America and is largely a result of repeated fires (Smithers, 1961; Wellner, 1970; Habek, 1976; Brown, 1975; Lotan, 1975a, 1976; Perry and Lotan, 1979). Successional trends are frequently interrupted by fire and original stands are replaced with essentially pure stands of lodgepole pine. Fire frequency seems to also affect cone serotiny in lodgepole pine stands (Lotan, 1976; Perry and Lotan, 1979; Muir and Lotan, In press). The effects of fire, fuel accumulation, stand development, and incidence of insects and diseases in lodgepole pine forests are all part of complex biological and physical relationships in what is oftentimes considered to be a simple ecosystem. The species has an amazing tenacity to survive a wide variety of environmental situations and to endure under differing fire regimes.

Brown's (1975) excellent review of the role of fire in lodgepole pine at the previous lodgepole pine symposium held in Pullman, Wash. in 1973, is a frequently cited reference. The current paper highlights pertinent relationships between fire and the species, for the most part in the Northern Rocky Mountains, and updates Brown's information. Fire regimes, fire behavior, fuel dynamics, community dynamics, succession, cone serotiny, stand establishment and development, and insect and disease relationships are discussed.

THE NATURE OF FIRE IN LODGEPOLE PINE FORESTS

That lodgepole pine forests occur over a wide variety of environments is a well established fact (Pfister and Daubenmire, 1975; Lotan and Perry, 1983). It follows then that the fire regimes affecting lodgepole pine forests also vary considerably (Brown, 1975; Arno, 1980; Kilgore, 1981; Martin, 1982). Fire regimes are the particular pattern of fire frequency and intensity occurring within a particular ecosystem (Kilgore, 1981). These fire regimes depend not only upon the vegetation and topography involved but also upon the climatic regimes that determine the coincidence of ignitions and the burning conditions.

Brown (1975) illustrated many interrelated factors that influence the fire regime in lodgepole pine forests (fig. 1). He pointed out that seedling establishment and subsequent development of stand density, age structure, and composition depend in part upon the type of fire that last occurred. In turn, characteristics of the developing stand influence the type of fire that will next occur and when it will occur (fire regime).

Fire Regimes

Fire Frequency

Arno (1980) concluded that fire has historically been more frequent in lodgepole pine than previously realized. He reported fire-free intervals of only 22 to 50 years in many lodgepole pine-dominated stands in the northern Rocky Mountains (table 1), yet some high elevation areas have fire-free intervals measured in centuries (Romme, 1980).

Fire-scarred lodgepole pine resulting from low-intensity surface fires are fairly common. Prior to the advent of fire suppression low-intensity surface fires were common in the Bitterroot National Forest in Montana (Arno, 1976), in Jackson Hole in Wyoming (Loope & Gruell, 1973), and in the Bob Marshall Wilderness in Montana (Gabriel, 1976). Although we know that most individual fires were low-intensity, creeping, surface fires, today most acreage burned is by the high intensity crown fires that occur during severe weather: dry and/or windy conditions. A particular fire regime in lodgepole pine forests greatly affects seedling establishment, stand density, age structure, and species composition.
Frequent low intensity fires may thin lodgepole pine stands without doing serious damage. They may also induce decay or disease outbreaks, or other events. Eventually fuel conditions become hazardous, weather becomes extremely dry, lightning or other incidents ignite fuels, and the stand burns, usually at the expense of associated tree species.

In some years the area burned is extensive. Barrows (1951) estimated that some 12 million acres (4.8 million ha) burned in the northern Rocky Mountains between 1908 and 1947. During the infamous 1910 fire season alone nearly 4 million acres (1.6 million ha) burned, much of it in lodgepole pine forests. Fire has no doubt burned all forest ecosystems at least once on the order of every few centuries. Fire is part of the history of Rocky Mountain lodgepole pine. The major ecological effect is the disruption of forest succession, and lodgepole pine usually capitalizes on this disruption.

Fire Behavior

In many lodgepole pine stands, fire is an "all or nothing" proposition: either smoldering and creeping over the ground or developing into rapidly moving, intense crown fires. Further, large, summer wildfires typically display both low- and high-intensity fire behavior triggered by diurnal weather changes as described in detail by Muraro (1971).

Most fires in lodgepole pine forests are of low intensity because surface fuel properties are not conducive to high flammability. Fires may go out in a day or two after they start or they may smolder in duff and rotten wood for weeks and even months without making sustained runs, as observed in Yellowstone National Park (Sellers and Despain, 1976). Fires are more flammable, however, in parts of Canada where Cladonia lichen is an abundant surface fuel on dry sites (Lawson, 1972). Fires here are more apt to spread as a flaming front but usually at low intensity. Lawson (1973) measured an average fireline intensity of 35 Btu/s/ft (range was 7 to 125 Btu/s/ft) for 28 test fires in fuels containing Cladonia, dwarf huckleberry (Vaccinium spp.), needle litter, and limited amounts of downed woody fuel. Spread rates averaged 2.6 ft/min (range was 0.9 to 6.5 ft/min). It required up to 48 minutes after ignition for fires to reach a steady state rate-of-spread. Mid-flame wind speeds ranged from 0.8 to 3.3 mi/h. Mathematical model predictions (Rothermel, 1972; Albini, 1976) for the Selway-Bitterroot fuel data (table 2) produced rates of spread and fireline intensities similar to those reported by Lawson. Fires in these fuels are marginally sustainable and easy to control by direct attack using hand tools.

The Shoshone National Forest data (table 2) exemplifies the high end of the flammability scale in lodgepole pine surface fuels. Predicted fireline intensities were several times greater (200 to 400 Btu/s/ft) than the other locations due to heavier loadings of litter and downed woody fuels. At low moisture contents these fuels have high potentials for crowning and spotting and indirect attack would probably be necessary to suppress fire.

High intensity fires are most probable where dead fuels have accumulated (fig. 2). Concentrations of dead fuels or mixed dead and live fuels cause torching of individual trees and groups of trees. High winds and steep slopes can then produce running crown fires. These may occur as narrow stringers of crown fire up the sides of steep mountains or involve much larger areas.
Table 2.—Average loadings of the forest floor litter layer, downed woody material less than 3 inches diameter and understory herbaceous vegetation and shrubs from large numbers of samples at different locations.

<table>
<thead>
<tr>
<th>Location</th>
<th>Plots</th>
<th>Litter</th>
<th>Less than 3&quot; woody material</th>
<th>Herbs &amp; shrubs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Selway-Bitterroot Wilderness, Idaho</td>
<td>360</td>
<td>0.6</td>
<td>1.4</td>
<td>0.94</td>
</tr>
<tr>
<td>Shoshone National Forest, Wyo.</td>
<td>190</td>
<td>1.1</td>
<td>4.0</td>
<td>0.28</td>
</tr>
<tr>
<td>Bitterroot National Forest, Mont.</td>
<td>400</td>
<td>0.3</td>
<td>3.4</td>
<td>0.92</td>
</tr>
<tr>
<td>Central British Columbia (Lawson, 1973)</td>
<td>--</td>
<td>0.2</td>
<td>0.5</td>
<td>0.17</td>
</tr>
<tr>
<td>Front Range, Colo. (Alexander, 1979)</td>
<td>365</td>
<td>1.4</td>
<td>2.7</td>
<td>0.13</td>
</tr>
</tbody>
</table>

The open, self-pruning crowns of lodgepole pine are less prone to crowning than species such as spruce and subalpine fir (*Abies lasiocarpa*) that have dense crowns often containing dead branchwood (Despain and Sellers, 1977). Fahnestock’s (1970) rating of crown fire potential places lodgepole pine as low as any conifer and with two to three times less crowning potential than closed-crown species. The likelihood of crowning fire in lodgepole pine depends on the heat from surface fuel and particularly the distance above ground to the crowns. Potential fire intensity and fire size depend, in part, on the spacing of trees and quantity of crowns per unit area. Thus, fire behavior potential of crown fuels depends upon stand conditions which, in turn, are frequently affected by the nature of the preceding fire. In this way, fire and stand development are mutually related (Brown, 1975).

In resistance to fire, lodgepole pine has traditionally been rated between the most fire-resistant western larch, ponderosa pine, and Douglas-fir and the least fire-resistant subalpine fir, western hemlock, and Engelmann spruce (Wellner, 1970 after Flint, 1930).

Rates of spread and fire intensities are not as great in forests composed of larch, Douglas-fir, western white pine, and cedar/
hemlock (Lyman, 1945), but are greater than in spruce, fir, and aspen. The duff of lodgepole pine dries rather rapidly (Smithers, 1961).

Brown (1975) reported comparative fire data from Barrows (1951):

**Ignition Potential.** – The number of fires per million acres:

<table>
<thead>
<tr>
<th>Species</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fir/larch</td>
<td>40</td>
</tr>
<tr>
<td>Lodgepole pine</td>
<td>50</td>
</tr>
<tr>
<td>Douglas-fir</td>
<td>70</td>
</tr>
<tr>
<td>Grand fir</td>
<td>410</td>
</tr>
</tbody>
</table>

**Rate of Spread.** – Averaged 132 ft (40m) of perimeter per hour from origin of fire to time of attack by suppression forces. This is the average for all forest types. It is greater than spruce/fir and less than for Douglas-fir and ponderosa pine.

**Fire Size.** – Only ponderosa pine exceeded lodgepole pine in percentage of fires greater than 10 acres (4 ha).

<table>
<thead>
<tr>
<th>Size</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than ¼ acre</td>
<td>76</td>
</tr>
<tr>
<td>Less than 10 acres</td>
<td>95</td>
</tr>
<tr>
<td>Less than 300 acres</td>
<td>99</td>
</tr>
</tbody>
</table>

**Ignition Potential by Fuel Type.** – Percentage by material first ignited.

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duff</td>
<td>36</td>
</tr>
<tr>
<td>Green treetops</td>
<td>5</td>
</tr>
<tr>
<td>Snags</td>
<td>30</td>
</tr>
<tr>
<td>Grass</td>
<td>10</td>
</tr>
<tr>
<td>Wood on ground</td>
<td>14</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>5</td>
</tr>
</tbody>
</table>

Although lodgepole pine is intermediate in fire potential when compared to other species, under certain conditions stand-replacing fires burn vast areas. Apparently, the long fire cycles lead to extremes in fire behavior.

### FIRE-STAND-FUEL INTERACTIONS

Stand structure, fuel succession, and fire, are interrelated. They all depend upon the nature of mortality that occurs during stand development (fig. 1). For example, an insect epidemic that causes considerable tree mortality also leads to an accumulation of downed dead fuel (fig. 2). In turn, the accumulation of fuel increases the chances of a high-intensity, stand-replacing fire. A high intensity fire has a different influence on regeneration than a low intensity fire. Finally, the composition and structure of a new stand influences its susceptibility to mortality.

**Mortality and Fuel Buildup**

In response to natural mortality and factors causing downfall, dead fuels accumulate on the ground. Causes of mortality such as fire, insects and disease, competition or natural thinning, and wind damage impact stands at erratic intervals. Thus quantities of downed woody fuel accumulate in an irregular manner not necessarily related to stand chronology. Because of irregular accumulation, prediction of downed woody fuel loadings in specific stands from characteristics of the stand has not proved reliable (Brown and See, 1981; Alexander, 1979; and Muraro, 1971). Quantities of lodgepole pine crowns that are potentially slash fuels following harvest, on the other hand, can be reliably predicted (Brown, 1978; Gary, 1976; Kiil, 1967).

- Stand development, vegetation mortality and fuel buildup, and fire interact dynamically in lodgepole pine forests (Brown, 1975). Historically, fire may have created more surface fuels than any other single cause of mortality. Subsequent fuel buildups vary depending upon fire intensity. In high-intensity fires, an entire stand is killed and eventually falls to the ground, creating a large fuel buildup. Low-intensity fires kill fewer trees and create less fuel. The thinning effect on the stand, however, opens it up to increased wind and sunlight, which increases flammability. Low-intensity fires may also decrease fuel loadings.

Suppression mortality begins soon after dense stands are established and can contribute significantly to surface fuels. Where crown competition is not severe, suppression mortality creates little fuel. The intensity of the preceding fire, which influences seedbed condition and seed supply, affects density of the new stand; thus, determines whether suppression mortality is a factor in fuel buildup.

Insects, particularly the mountain pine beetle *Dendroctonus ponderosae* Hopk., create ground fuels by killing trees and opening up stands for drying. Today, this cause of mortality probably overshadows all others as a cause of fuel buildup.

Diseases such as root rots and canker rots can cause ground fuel buildups of local importance; however, they are of less importance than other sources of mortality. Low-intensity fires can encourage rot infections by forming basal fire scars that serve as entry points for pathogens (Nordin, 1958). Fire-scarred trees subsequently infected by fungus also appear to be selectively killed by beetles (Geiszler, 1980). Recent investigations indicate that root damage from burnout of large woody fuel may be the most important source for stem decay (Gara and others, this proceedings). This suggests an interesting link between fire, disease, and fuel buildup. Another pathogen, dwarf mistletoe, *Arceuthobium americanum*, can add significantly to surface fuels particularly in older stands.

The presence of dwarf mistletoe and mountain pine beetle in lodgepole pine stands increase flammability of the stand. The
mountain pine beetle by attacking and killing mature to over- 
mature trees increases the heavy fuel loads in the stand at a 
time when the stand itself is approaching a high fire hazard.

Dwarf mistletoe by decreasing the tree growth has been 
suspected of predisposing the tree to mountain pine beetle and 
accelerating fuel build-up, but evidence has not been substan-
tiated. In the absence of mountain pine beetle, dwarf mistletoe 
increases fire hazard by stimulating epicormic branching of the 
 tree, thereby enhancing vertical continuity.

Though lodgepole pine, mountain pine beetle, and dwarf 
mistletoe all influence characteristics of fire, fire itself often 
enhances potential fire behavior of future fires. The intensity 
of fire will have a role in determining stand density and future 
fuels potential. For instance, a high-intensity fire will usually 
be followed by a dense stand due to opening of serotinous cones 
and exposed mineral soil.

Breakage from wind and snow and other specific causes of 
mortality contribute to buildup of downed woody surface fuels. 
Thus we have interrelationships among many variables, with 
some processes governed by laws of chance. This means man-
gement actions can have far reaching effects on fuels and stand 
development, and that prediction of surface fuels requires more 
than just knowledge of stand characteristics. Stand history is 
extremely important.

Fuel Accumulation and Fuel Succession

Fuel accumulation refers to an increase in fuel quantities over 
time. Fuel succession is the change in fuel characteristics over 
time and involves both increases and decreases in fuel quan-
tities and is the term preferred by the authors because it more 
nearly describes what takes place over time. Vegetative biomass 
increases regularly over time; however, all biomass is not fuel. 
Decay of fuel can be greater than accretion, resulting in a net 
decrease in fuel. Thus, the term fuel succession more correctly 
describes the dynamics of fuel with time (Brown, In Press). In 
lodgepole pine forests as perhaps in all forests, live and dead 
fuels as well as small and large fuels can follow different suc-
cessional patterns. Changes in fuel quantities are better 
documented in lodgepole pine forests than perhaps for any other 

Quantities of forest floor litter comprising foliage, bark flakes, 
twigs, and stems less than about 1 inch in diameter remain fairly 
constant over time while crown canopies are closed (Alexander, 
1979; Jeske and Bevins, 1979). Small oscillations in litter loading 
occurred (Fahnestock, 1976) probably due to the variable effects 
of wind and snow on the shedding of dead and live crown 
material.

Shrub and herbaceous understory fuels have been reported 
to vary from 0 to 8 tons/acre (Alexander, 1979), but lodgepole 
pine forests characteristically support small quantities of 
understory vegetation (table 2). Quantities vary by site (Trappe 
and Harris, 1958) and species composition. High loadings of 
understory fuel are primarily comprised of shrubs. Changes in 
understory biomass apparently depend on site conditions and 
species existing before disturbance (Lyon and Stickney, 1976; 
Habeck, 1976), as well as on the nature of disturbance. On mesic 
sites, biomass of herbs and shrubs tends to peak during early 
stages of stand development and to decrease after that.

Forest floor duff (fermentation and humus layers) increases 
with time since disturbance by fire. The rate of increase levels 
off when a balance between accretion and depletion is reached. 
Depletion is caused by decay and occurrence fires. The time 
required for duff accumulation to reach equilibrium is difficult 
to measure because of the confounding influence of low-
intensity fire. It may occur soon after 100 years as observed 
along the Colorado Front Range (Alexander, 1979) or after 300 
years as observed in Yellowstone National Park (Romme, 1980).

Duff depths in the Northern Rockies typically range from 
0.2 to 1.6 inches (0.5 to 4 cm) (table 3) and accumulations ap-
pear to be uninfluenced by aspect (Brown and See, 1981). In 
Colorado, however, Alexander (1979) and Zimmerman (1982) 
reported 3 to 4 inches (9-10 cm). Duff loadings corresponding 
to these depths range from 3.3 to 26 tons/acre based on a 
characteristic bulk density of 9 lb/ft³ (Woodard and Martin, 
1980; Brown 1974).

In terms of fire behavior, the most significant fuel compo-
nent in lodgepole pine forests is dead, woody material. Large 
fuel (pieces greater than 3 inches in diameter) makes up most 
of the dead material. In unlogged stands, quantities of large 
fuel typically range from 0 to 20 tons/acre (table 3), with a max-
imum of 60 to 90 tons/acre possible after downfall of a com-
pletely killed stand (Brown, 1975). Stands rated high risk in 
the Forest Service, Northern Region contained twice the large 
fuel loadings as other stands. Large fuel loadings were greater 
on north aspects than south aspects but did not vary signifi-
cantly with elevation (Brown and See, 1981).

Table 3.—Fuel loadings based on planar intersect sampling of timber stands on National Forests in the Northern Region (Source: Brown and See, 1981).

<table>
<thead>
<tr>
<th>Location</th>
<th>Fuel</th>
<th>Eastern Mont. (3,400 samples)</th>
<th>Western Mont., Idaho (4,172 samples)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>mean</td>
<td>median</td>
</tr>
<tr>
<td>Duff depth, inches</td>
<td>1.1</td>
<td>0.8</td>
<td>1.1</td>
</tr>
<tr>
<td>Woody material</td>
<td>13.9</td>
<td>4.7</td>
<td>14.4</td>
</tr>
<tr>
<td>&gt;3 inch, tons/acre</td>
<td>16.0</td>
<td>7.0</td>
<td>18.0</td>
</tr>
<tr>
<td>Total woody material, tons/acre</td>
<td>16.0</td>
<td>7.0</td>
<td>18.0</td>
</tr>
</tbody>
</table>

Fuel succession in lodgepole pine is exemplified by lack of 
consistent patterns. In figure 3, median large fuel loadings were
normalized using the maximum loading for each of three studies. Loadings of down woody fuel from northern Idaho and western Montana increased continuously with age. In Glacier National Park (Jeske and Bevins, 1979), such fuel loadings decreased until stands were about 100 years old, then they increased. Romme (1980) observed a similar pattern in Yellowstone National Park but the increase began at a stand age of about 200 years. In the Selway-Bitterroot Wilderness, Idaho, the loading trend was the reverse of that in Glacier National Park. In lodgepole pine on the Colorado Front Range, Alexander (1979) found no consistent pattern in loading and stand age.

Fuel succession for lodgepole pine (and probably other species) shows two trends: (1) fuel quantities are usually high as stands become overmature, but (2) fuel quantities cannot be predicted from age alone in young immature or mature stands.

Fuel variation in younger stands relates to the size of trees killed by previous fire and the interval until the next fire. High loadings in the juvenile period result from downfall of dead trees from the previous stand. Considerable time may be required for trees from the previous stand to decay and settle into the forest floor. If fire consumes most of the downfall during the juvenile period, the next stand will have much smaller downed fuel loadings during the juvenile period.

Fire- or beetle-killed lodgepole pine begin to fall 2 to 5 years after dying; most trees will be down in 15 years (Lyon, 1977; Flint, 1924). Some large-diameter trees will stand longer. This pattern supports fire specialists who contend that fire hazard in lodgepole pine peaks 25 years after a burn (Lyman, 1945). In 25 years most fire-killed trees would have become surface fuel lying in contact with crowns of regenerating lodgepole pine. The same fire specialists believe that the hazard declines 50 percent from its peak in 35 years and returns to a moderate level some 85 years following the fire. Mason (1915) suggests that fire-killed timber decays in 60 to 120 years. This agrees with Alexander’s (1979) study that shows loadings of rotten large fuel to be greatest in stands 40 to 100 years of age.

Potentials for high-intensity fire are greatest when growth of conifers creates crown fuels in close proximity to large accumulations of dead woody fuel. This condition can occur twice during the life of a stand. The first critical period occurs during the juvenile stage as described above. A burn during this period may consume most of the woody fuel so that the ensuing stand develops with a low fire behavior potential. The second period occurs when the lodgepole pine stand begins to break up and accumulates dead surface fuels in an understory of developing spruce or fir. Stand age for the second period depends on longevity and can vary from 100 years (Trappe and Harris, 1958) to as much as 400 years (Romme, 1980).

Hazard Evaluation

Fire hazard in lodgepole pine stands varies with the development of the stand (Brown, 1975). In young, dense stands and in overmature stands with an understory of shade-tolerant conifers, the hazard of fire is high. In moderately dense to open mature lodgepole pine the fire hazard is low. This is an advantage for a seral species because a fire in an overmature stand will kill the shade-tolerant understory species and provide a seedbed for regeneration of lodgepole pine. A similar fire would kill a dense, young stand, but the fewer cones at that time would produce less, resulting in lower stocking (Brown, 1975). Fire history studies have indicated that understory fires sometimes killed understory species without damaging the lodgepole pine overstory.

Over the past 10 years several methods have been developed for appraising fuels, fire behavior, and hazard. Stylized fuel models used in conjunction with the National Fire Danger Rating System (NFDRS) or the Fire Behavior Prediction System (FBPS) are appropriate for broad resolution (Anderson, 1982). Lodgepole pine levels are usually modeled as follows:

<table>
<thead>
<tr>
<th>Timber group, normal fuel accumulations; low flame lengths</th>
<th>NFDRS</th>
<th>FBPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timber group, heavy fuel accumulations, greater intensities</td>
<td>G</td>
<td>10</td>
</tr>
<tr>
<td>Slash</td>
<td>I, J, K</td>
<td>11, 12, 13</td>
</tr>
</tbody>
</table>

A photo series for appraising nonslash downed woody fuels (Fischer, 1981) and residues (Maxwell and Ward, 1976) in the lodgepole pine type is an easy-to-use, site-specific method. It consists of photographs of varying quantities of fuel and descriptions of fuel loadings, stand descriptions, and fire behavior.
ratings. Fuels observed in the field are compared to photographs for making appraisals.

The greatest resolution in appraisals is provided by inventorying existing fuel quantities or predicting crown weights (Brown and others, 1977). Rates of spread and intensities are then predicted from the fuel quantities and can be further subjected to principles of decision analysis to produce estimates of expected burn areas (Hirsch and others, 1981; Puckett and others, 1979). Hazard also can be classified based on relationships between the Canadian Fire Weather Index and field measurements of rate of spread and intensity (Lawson, 1973; Quintilio, 1972).

Fuel inventory coupled with fire behavior modeling is the most technically elaborate technique for appraising the effects of management actions on fuel and fire behavior. For example, in a study of alternative harvesting practices in lodgepole pine, conventional logging resulted in fireline intensities one year after cutting that were six times greater than in intensive residue removal (everything larger than a 3-inch diameter and 8-foot length removed) (Brown and Lotan, 1982). Intensities for broadcast fire on clearcuts with conventional logging exceeded 500 Btu/s/ft, often considered an unacceptable hazard, for windspeeds greater than 10 mi/h. After 5 years, however, intensities were only slightly greater under conventional logging due to needle drop and settling of slash. In two separate studies of fire hazard in precommercially thinned lodgepole pine, potential rate of spread was increased 3 to 5 times by thinning (Hawkes and Lawson, 1980, Alexander and Yanick, 1978).

Fire behavior modeling must be applied with awareness of limitations in the model. For example, the Rothermel (1972) spread model assumes uniformly distributed fuels and pertains only to a propagating flame front supported by fine surface fuels. Fire behavior caused by combustion of large fuels is not modeled. Although fire behavior modeling allows managers to appraise fire potentials quantitatively and consistently, experienced judgement is essential to proper interpretations.

### FIRE ECOLOGY

#### Fire Effects on Succession

Lodgepole pine is an aggressive seral species that readily establishes itself on disturbed areas, including burned areas (Clements, 1910; Mason, 1915; Horton, 1953; Smithers, 1961). Bare, mineral soil provides the best seedbed for lodgepole pine. This fact is readily observed on disturbances such as roadsides, powerlines, or on most clearcut or burned areas.

Because of its ability to grow on almost any forest site, lodgepole pine occurs in a wide range of forest types. It therefore displays a variety of successional roles that are controlled partly by the environmental conditions and partly by competition from associated species adapted to the site. Successional variation can be defined in four basic successional roles for lodgepole pine (Pfister and Daubenmire, 1975):

1. Minor seral. A component of young even-aged stands being rapidly replaced by shade-tolerant associates in 50-200 years.
2. Dominant seral. The dominant cover type of even-aged stands with a vigorous understory of shade-tolerant species that will replace the lodgepole in 100-200 years.
3. Persistent. The dominant cover type of even-aged stands with little evidence of replacement by shade-tolerant species.
4. Climax. The only tree species capable of growing on a particular environment, i.e., self perpetuating.

Some persistent stands of lodgepole pine are the result of repeated fires that have eliminated seed sources of other species (Tackle, 1961; Lotan, 1976; Lotan and Perry, 1983). Other stands are pure lodgepole pine because site conditions are such that no other tree species can survive (Despain, 1973; Moir, 1969; Franklin and Dryness, 1969).

Without periodic fire lodgepole pine tends to be replaced by more shade-tolerant species such as Douglas-fir, Engelmann spruce, and subalpine fir. In fires in mixed stands the proportion of lodgepole pine will increase with each recurring fire. Only western larch approaches the tenacity with which lodgepole pine recolonizes a disturbed site.

Lodgepole pine succession is regulated by several biotic and abiotic factors. Some of the major biotic factors regulating this succession are: the growth characteristics of lodgepole pine itself, the mountain pine beetle, and dwarf mistletoe. Fire is an important abiotic factor in successional regulation. Important characteristics of lodgepole pine that contribute to its aggressive capability to recolonize a site are a readily available supply of seed and rapid juvenile growth.

Extensive stands of lodgepole pine are found in the Douglas-fir and spruce-fir climax series (Pfister and Daubenmire, 1975; Wellner, 1975). In these series extensive areas have burned during severe fire weather.

The effects of low-intensity fires in lodgepole pine stands depends upon availability of seed and amount of duff removed. In pure stands of lodgepole pine, nonserotinous cones provide seed for surface burns. Surface fires do not open the serotinous cones in the crown. Most stands have sufficient open-coned trees to provide abundant seed (Mason, 1915; Lotan, 1970). In mixed stands the composition of regeneration is generally similar to that of the overstory, but resistance to fire will favor some species over others.

High-intensity fires in pure lodgepole pine stands usually result in a new stand of pure lodgepole pine. In this case the high biotic potential in seed stored in serotinous cones is of great importance in the establishment of extensive areas of pure, dense, lodgepole pine. Seed is accumulated for decades.
Quantities of seed equal to 10 years annual production is available for recolonizing a site (Lotan, 1975a, 1976). Millions of sound seed per acre are often available. This abundant supply of seed combined with rapid juvenile growth make the species a formidable competitor in stand establishment.

Lodgepole pine, when disturbed, will colonize open sites with mineral soil seedbeds and grow faster than most other conifers invading the site. Depending on site conditions, lodgepole pine will continue this growth for 30 to 80 years before it begins to slow down. After about 80 years, the growth rate of lodgepole pine will slow significantly while the growth rate of more shade-tolerant species in the understory increases. At about this time (80 years), the understory tree species will begin to overtop the lodgepole pine (Eis and others, 1982).

The influence of insects, disease, and fire often interrupt this succession and prevent its progression to climax vegetation. In the absence of fire or other disturbances, and except where it is climax or persistent, lodgepole pine will decrease in the ecosystem because of its inability to compete with shade-tolerant tree species.

The effects of fire intensity on stand establishment, as discussed by Brown (1975) and Muraro (1971), can be briefly stated as:

**High Intensity Fire**

1. Creates good seedbed conditions on mesic and wet sites, and when seed is abundant, dense stands are established. On dry sites, however, low stocking can result because of poor moisture conditions.
2. Crown fires usually cause maximum release of stored seed. In surface fires with considerable crowning, mineral soil is exposed, serotinous cones open, and if seed is abundant a dense stand results. Occasionally, severe crown fires consume up to ½-inch-diameter fuel, destroy much of the seed supply, and a lower density stand results.
3. When seedbed conditions, seed supply, soil moisture, and other factors are favorable for stand establishment, extremely high stocking (leading to stagnated stands) frequently results.
4. Competition from understory vegetation, particularly grass, can decrease stand density even if other factors influencing establishment are favorable.

**Low-Intensity Fire**

1. Moisture content of duff is an important factor in determining level of stocking. When duff is dry a low-intensity fire will expose mineral soil, resulting in a high level of stocking. When duff is moist, fire will expose less mineral soil, resulting in poor seedbed conditions and low stocking.
2. Mortality may be minimal or sporadic. Sometimes widely spaced stands result. In time, two-aged or three-aged stands can develop.
3. In stands of mixed species, the survival of lodgepole pine depends on its fire resistance relative to other species as well as the seed potential of all species. Post fire species composition, age structure, and density of mixed stands vary considerably, depending upon fire characteristics and many other interrelated factors.

Though lodgepole pine is a fire-adapted species, fire management must carefully consider the dynamic relationships occurring within different lodgepole pine communities. Fire may occur at various points during succession and have different effects.

Fischer and Clayton (1983) gave a generalized depiction of forest succession for cool habitat types usually dominated by lodgepole pine (fig. 4). The climax forest indicated within the circle is usually not reached. In most of these forests, fire cycles maintain the dominance of lodgepole pine. The short-lived herb/shrub stage often provides forage for livestock or big game, but fires are not likely in this stage. In Eastern Montana, the Cross Creek Fire burned around a logged area that was in this stage (personal observation, 1984). Fischer and Clayton's
summary is an excellent reference for details on fire as an ecological factor for forest habitat types in the northern Rocky Mountains.

**Other Factors**

In addition to fire, climatic and edaphic characteristics promote pure stands of lodgepole pine. In much of the commercial lodgepole pine in the Rocky Mountains, the climate during the growing season is reasonably similar. Although precipitation decreases from west to east, the proportion of summer rainfall increases. Overall climatic generalizations in the lodgepole pine region are: snowfall is heavy and supplies the major portion of soil water used for growth in early summer; winter temperatures are cold; summer, especially in July and August, has relatively low rainfall; and in many areas, especially in basins and other cold-air pockets and at high elevations there is no true frost-free period (Lotan and Perry, 1985). Lots of exceptions occur. For example, in Colorado summer precipitation is more abundant after a dry season in May and June.

When species are viewed on an elevational gradient, lodgepole pine often occupies the middle, moderately mesic environment. Often where it is climax, the soil moisture or other site conditions are extreme: either seasonally ponded soils or well drained-droughty sites (Pfister and Daubenmire, 1975). Lodgepole pine often occurs on sites that are droughty or where other species are unable to grow (Moir, 1969; Stephens, 1966). In other areas, lodgepole pine is tolerant of high water tables or flooding (Minore, 1968; Cochran, 1972), and extreme frost pockets as in central Oregon.

Although lodgepole pine occurs on a wide range of soils, the species does best on soils derived from granite, shale, and course-grained lavas (Tackle, 1961; Despain, 1973). The effects of soil properties and soil moisture result in local situations favoring lodgepole pine over other species.

Lodgepole pine often grows under nutrient conditions less than optimal for other conifers, with nitrogen the most limiting element. It is often the only conifer that will grow on extremely infertile soils (Stephens, 1966; Despain, 1973). Near West Yellowstone, Mont., the establishment of lodgepole inversely related to the amount of nitrogen and potassium in soils (Stermitz and others, 1974). It simply grows where other conifers cannot.

Lodgepole pine may occupy a low nutrient niche, either through an extremely low nutrient requirement (van den Driessch and Waring, 1966) or an ability to extract nutrients that are unavailable to other species (Lewis and Eisenmeuser, 1948; Stone and Fischer, 1969). Despain (1978) has suggested that lodgepole pine stands may have evolved to maintain a low soil nutrient status and thus avoid direct competition with other, more nutrient-demanding species.

Higher accumulation of nutrients in the forest floor has been observed in lodgepole pine stands than in other pine-dominated ecosystems (Jenny and others, 1949; Moir and Grier, 1969). Fahey (1983) found that nutrient returns in annual litter fall are much lower in lodgepole pine ecosystems than in most forest types that have been studied because of low litter fall mass and low element concentrations in leaf litter. The accumulation of mass and nutrients in the forest floor was high, considering the low rates of litter deposition. Thus, residence times for organic matter and nutrients were considerably longer than those which have been calculated for pine forests from warmer and/or more moist climates.

**Cone Serotiny**

Although the thin-barked lodgepole pine is fairly susceptible to fire, the serotinous cone habit enables it to regenerate large areas after disturbance. The persistence of a lodgepole pine forest cover over such vast areas is directly attributable to its ability to disperse vast amounts of seed upon a freshly prepared seedbed. Millions of sound seed per acre are stored within the serotinous cones in mature stands (Lotan, 1967, 1968).

This ability to regenerate vast areas is not due to the serotinous cone habit alone. Seed viability, germinative energy, rapid juvenile growth, prolific seed production, and ability to survive a wide variety of microsite and soil situations all contribute to its aggressive nature in these situations (Haasis and Thrupp, 1931; Critchfield 1957, 1980; Lotan 1975, 1976; Lotan and Perry 1983; Illingworth 1975). Of all these traits cone serotiny is a key factor because of its potential for storing large numbers of seeds that can be released all at one time upon a freshly prepared seedbed.

Because of its impact upon stand regeneration, the serotinous cone habit must be considered in any management program involving lodgepole pine in much of the range of lodgepole pine. The proportion of serotinous-coned type trees in a stand varies considerably (Lotan, 1975). Bates and others (1929) pointed out, however, that fire is not absolutely necessary to open serotinous cones. Serotiny can be broken from heat near the soil surface during summer weather (Crossley, 1956; Lotan, 1964b).

Lotan discussed variability of cone serotiny in the previous lodgepole pine symposium in Pullman, Wash. (Lotan, 1975a) and at a Tall Timbers Meeting in Missoula, Mont. (Lotan, 1976). Critchfield (1957) reported general variability in his descriptions of the four subspecies of lodgepole pine: Critchfield showed us that Rocky Mountain and Mendocino Plains stands tend to bear persistent, asymmetrical, obliquely attached, hard, and serotinous cones. Cones on lodgepole pine in the Sierra Nevada are deciduous, symmetrical, fragile, and consistently

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1. Despain, Don G. 1978. (Personal communication) Yellowstone National Park, WY.
open. Critchfield considered cones of shore pine along the west coast, in the Blue Mountains of Oregon, and in the Cascade Mountains as intermediate in cone traits.

Although Rocky Mountain populations have been considered to be the serotinous-coned type, Lotan's studies (1975a) showed that variation does occur even in Rocky Mountain stands. Elevational clines were found in local areas (Colville National Forest), but throughout the study area these relationships were maintained. The range of elevations sampled throughout the study was from 2,100 ft (~640 m) to 10,200 ft (~3090 m). The proportion of serotinous-cone type trees within in a particular stand ranged from 0 to more than 80 percent throughout the Northern Rocky Mountains.

Variation within a stand is usually quite low. Often variation within a drainage is low, with sharp boundaries between populations. It appears that the base population is open-coned, with the closed-cone trait occurring as swarms within the base population.

Critchfield (1957) suggested fire as the selective agent primarily responsible for the evolutionary divergence in one habit between Rocky Mountain and Sierra Nevada populations. The Rocky Mountains are known for stand-replacing fires at least in some years compared to the Sierra Nevada where stands have commonly burned with light surface fires. Further, Lotan (1967) compared serotiny in an even-aged stand of recent fire origin with a contiguous unvene-aged stand. The even-aged stand would have originated primarily from seed released from cones opened by fire. The uneven-aged stand regeneration would have been established from an annual seedfall from open-coned trees. Fifty-eight percent of the even-aged stand had serotinous-cone type trees compared to only 38 percent of this type tree in the uneven-aged stand.

It is difficult to develop a relationship between fire regimes and cone serotiny over broad areas, however, because of the many confounding variables involved. Perry and Lotan (1979) developed a hypothetical model of fire selection for cone serotiny that indicated that gene frequencies for the closed cones was particularly sensitive to stand-replacing fires while accounting for the large population of open-coned type trees, sampled in Lotan's (1975a) study. Muir and Lotan (In press) collected data on the Bitterroot National Forest in Montana that substantiated the hypothetical model—their study showed that the degree of cone serotiny depends greatly upon the nature of the last disturbance, and that a large proportion of these trees are open-coned.

In the Rocky Mountains where cone serotiny appears to be the most common, lightning-caused fires have no doubt been a strong selection force for the closed-cone habit. The serotinous cone habit in lodgepole pine is an "adaptive trait," i.e., one that facilitates survival and/or reproduction of its carrier. We must be careful not to presume selection because traits enhancing survival during fires may also enhance survival during stress from other environmental factors.

Prediction equations have been developed to estimate seed stored in closed cones of the canopy (Lotan and Jensen, 1970; Lotan, 1975a). This knowledge, together with information on seed: seedling ratios for particular habitat types, topographic situations, and climates, helps to explain much of the variation in natural reproduction in lodgepole pine (Lotan and Perry, 1983). Seed from open cones can be estimated from conventional seedtraps.

**Natural Regeneration**

Lodgepole pine is usually considered to be a prolific seed producer. Good seed crops occur at 1-3 year intervals, with light crops intervening (Tackle, 1961; Lotan and Perry, 1983). Lodgepole pine may start bearing cones at less than 10 years of age. Because of small seed, lodgepole pine seeds travel further than many others, but usually not over 200 ft (60 m).

The viability of lodgepole pine seed remains relatively stable even in old cones on trees for many years. Released seeds do not remain viable in appreciable numbers longer than one year.

Germination under field conditions is highly variable, depending on climate conditions and seedbed type. Experience in the Rocky Mountains has generally indicated that mineral soil seedbeds are superior for germination (Tackle, 1961 rev.; Lotan, 1964a; Prochnau, 1963; Blake, 1976). Germination is poor with maximum temperatures below 60° F and seems to be optimum in the range of 70° to 80° F, with fluctuating diurnal temperatures (Bates, 1930; Hassis and Thrupp, 1931). Seedling germination is rapid following snowmelt when both day and night temperatures are favorable (Lotan, 1964a). When soil moisture is sufficient, germination of seed is apparently unaffected by seedbed type (Fisher, 1983; Minore, 1972).

Disturbed mineral soil generally results in not only the best germination but also the best seedling survival (Lotan, 1964a; Alexander, 1966; Lotan and Dahlgren, 1971; Lotan and Perry, 1977b; Schmidt and Lotan, 1980; Schmidt, 1982), although disturbed duff or undisturbed duff that is not over one 1 inch thick may also give good results, particularly on moist sites (Tackle, 1956; Ackerman, 1957). Stocking is generally poor on deep duff and ash surfaces. The mere presence of lodgepole pine on various habitat types implies a history of site disturbance.

Seedling mortality varies greatly with soil type and seedbed condition. Survival is enhanced by good water-holding capacity, but is reduced by rising amounts of nitrogen and potassium, which foster competition from grass and forbs (Stermitz and others, 1974). New lodgepole pine seedlings are vulnerable to drought because of a relatively weak, slowly developing root system. Noble (1979) reports one-season rooting depths of less
than 4 inches. Shallow roots is a major factor contributing to mortality on both mineral soil and undisturbed areas. Lotan (1964a) noted significantly longer roots on prepared seedbeds compared to control plots with heavy grass competition. This may account for the belief that lodgepole pine seedlings have difficulty in competing with other vegetation, and grass provides the most competition.

Drought is a common cause of mortality among first-year lodgepole pine seedlings (Lotan, 1964a). In greenhouse studies, watered seedlings receiving less than 2 inches per month had low survival (Sheppard and Noble, 1976; Perry and others, 1978).

It is unlikely that nutrient deficiency is a serious cause of mortality in lodgepole pine. DeByle (1980) showed nutrient levels on different prepared seedbeds were greater or similar to undisturbed forest soils. Also by the second year, seedlings have presumably developed a root system and mycorrhizal associations that exploit the site efficiently.

**MANAGEMENT IMPLICATIONS**

Though lodgepole pine is adapted to fire, fire management must carefully consider fire and ecosystem relationships. Variability is common in lodgepole pine. Although the species is usually seral and even-aged, it is not uncommon to find multi-aged stands. Insects and disease greatly impact these forests, particularly the mountain pine beetle and dwarf mistletoe. Fires may occur at any point in the history of the stand and the effect of fire will vary greatly depending upon characteristics of the fire and the condition of the stand.

**The Use of Natural Fire**

Because of its widespread occurrence, lodgepole pine is frequently the forest of wilderness, national parks, or other areas managed for natural ecosystems. Here natural processes are allowed to function with a minimum of interference by man. Fires ignited by natural means such as lightning are considered natural processes. Most authorities agree that, with due consideration for human life, property, and resources outside natural ecosystems, lightning fires be allowed to burn under prescribed conditions.

There is some argument and precedent for using prescribed fire with deliberate, scheduled ignitions in parks and wilderness. In some areas 50 to 75 years of effective fire control has altered the historical fire regime thus resulting in unusual amounts of fuel and stand conditions. These areas are then susceptible to unusual fire behavior. The use of prescribed fire ignited by trained professionals and under carefully controlled conditions would permit subsequent use of natural fires without high fire hazard. Also some designated natural areas are too small for naturally ignited fires to be effective. The National Park Service currently uses prescribed fire. The USDA Forest Service is now studying the possibility of conducting prescribed burns in wilderness.

**Fire Management for Multiple Use**

In most lodgepole pine forests, use of prescribed fire has been limited to slash disposal and site preparation in connection with clearcut logging (Fischer and Clayton, 1983). Many of these lodgepole pine forests are seral stands in the Douglas-fir, Engelmann spruce, and subalpine fir habitat series. Lodgepole pine, spruce, and fir have relatively low fire resistance, and all are susceptible to fire damage. Further, in safe fire weather these forests are hard to burn. Burning must be done under dry conditions, therefore prescriptions must be written for a rather narrow prescription “window.” Broadcast burning is possible, and when properly used, is an environmentally and economically sound management tool (Lotan and Perry, 1977a; Zimmerman, 1982; Brown and Lotan, 1982; Lotan, 1982; Schmidt, 1982).

Although several even-aged silvicultural systems may be used to regenerate lodgepole pine, the general practice is to clearcut to obtain natural regeneration (Lotan, 1975b; Lotan and Perry, 1983; Alexander and others, 1983). Lodgepole pine is susceptible to windthrow when the stand is partially cut. Partial cutting hampers the use of fire because of lodgepole pine's susceptibility to fire damage. When stands are clearcut, piling and burning is commonly practiced, but broadcast burning is sometimes used (Lotan and Perry, 1977a; Zimmerman, 1982). Broadcast burning not only increases the yield of forage for big game and livestock, it was the preferred site treatment when wildlife, water values, and esthetic quality were considered (Benson, 1982).

Slash disposal methods are discussed in the proceedings of the previous symposium on lodgepole pine (Lotan, 1975b) and in the summary publication by Lotan and Perry (1983). A summary is provided here. Slash disposal should not be conducted solely to reduce the fire hazard because improper handling of slash can result in considerable loss of seeds contained in closed cones. Seed losses may reach 90 percent or more but can be kept below 25 percent with proper slash-handling techniques (Lotan and Perry, 1983). Timing is important. Losses may be high, particularly if treatment of slash is prolonged until after germination. Feller (1982) reported some disparity amongst published reports over desirability of slash-burning in lodgepole pine, but broadcast burning is not detrimental if prescriptions are carefully done (Brown and Lotan, 1982; Zimmerman, 1982; Lotan and Perry, 1977a). Soil is damaged only under large piles that should not represent more than 25 percent of the area. This is currently being investigated in a cooperative study among the scientists at the Northern Forest Fire Laboratory in Missoula and the University of Idaho. Muraro (1971) developed a prediction system to control the reduction of duff and slash fuel and predict the amount of mineral soil exposed.

Significant differences in seed:seedling ratios may be obtained with various seedbed conditions (Lotan and Perry, 1983).
Seedling survival is best on bare mineral soil, but some protective cover may be beneficial, depending upon slope, aspect, and location (Lotan, 1964a, Alexander 1966, Lotan and Dahlgreen 1971, Lotan and Perry 1977a). Disturbed duff and undisturbed duff less than one inch (2 to 3 cm) will yield good regeneration and survive on moist sites (Tackle, 1956; Ackerman, 1957). Deep ash makes a poor seedbed.

Some cover may be beneficial on extremely droughty sites (Lotan and Perry, 1983). Tackle (1956) found that stocking under logging slash less than 1 ft (30 cm) was as good as bare, mineral soil. Kovalchik and Blake (1972) found that areas treated with a roller chopper had as many seedlings as areas that had been piled and burned. Roe and Schmidt (1964) found a moderate vegetative cover to be beneficial.

Slash hazard can be abated and duff can be reduced to prepare the seedbed for natural regeneration, using broadcast burning when prescriptions and execution are carefully done. When environmental consequences are considered broadcast burning is a treatment that approximates natural processes (Lotan and Perry, 1977a; Schmidt and Lotan, 1980; Benson, 1982).

There are only a few guides for broadcast burning in lodgepole pine and there is much variability to consider. Zimmerman (1982) developed preliminary guides for broadcast burning lodgepole pine slash in Colorado. Quintilio (1970, 1972) developed preliminary guides for prescribed burning in southwestern Alberta.

Zimmerman's recommendations are:

- Temperature: 54-70°F (12-21°C)
- Relative Humidity: 25-40 percent
- Windspeed: 0-6 m/h (1-10 k/h)
- 10-hr. Fuel Moisture: 9.5 to 12.5 percent

These were the conditions that worked for Zimmerman. He realized that different weather conditions might also be successful. In fact he has completed successful burns with wind speeds as high as 18 m/h (30 km/h). Quintilio's guides relate rate of head-fire spread and depth of burn to components of the Canadian Forest Fire Weather Index System.

Adams (1972) showed good stocking using broadcast burning, but did not provide conditions for burning. Our own studies at Union Pass, Wyo., showed excellent results using broadcast burning when compared to other logging and post-logging treatments (Benson, 1982). We burned in the spring only two to three weeks following snowmelt. Fuel moistures were higher than prescribed but winds were a constant 15 mi/h (24 km/h). Burning was conducted on a June evening between 1900 and 2200 hours. Ignition followed a pattern from the center to the edges of the unit; a smoke column was created, and the strong, steady breeze kept it at a 45 degree angle. Some adjacent timber was scorched where heavy concentrations of slash had been windrowed (Brown and Lotan, 1982). As a general rule, burning in lodgepole pine has to be done with fairly dry fuel moistures or with a steady breeze. Some fire management officers successfully burn the type, but their methods have not been published. For maximum exposure of mineral soil, Shearer (1975) recommends burning in October. His relationship of duff reduction to duff moisture content is shown in figure 5.

![Percentage of duff reduction](image)

Figure 5.—Duff reduction related to moisture content of the lower half of duff layer (from Shearer, 1975).

Harvesting over-mature stands under current utilization standards leaves large quantities of logging debris (Benson, 1982) which is why reduction of fire hazard has always been a prime consideration in site preparation. Demand for firewood has changed total utilization in many areas and new techniques and better utilization will no doubt lessen slash hazard, but nevertheless, fire will remain useful in managing lodgepole pine far into the future. With the variability in both understocking and overstocking of the species, much can be gained by proper handling of logging slash.

Large areas of lodgepole pine have been harvested and the potential for harvesting even more is great. Lodgepole pine is one of the most under-utilized species in the Rocky Mountains (Koch, this proceedings).

Once these stands have been regenerated, we must protect a rather large investment, particularly the prevention of stand-destroying fires over large areas. One solution is to create a fully regulated forest with a good distribution of age classes. This will minimize the danger of having large, extensive stands of trees that are all of the same fire hazard. This same strategy will assist greatly in minimizing insect or disease pandemics.
The Use of Fire in Controlling Insects and Disease

The two most serious pests of lodgepole pine are the dwarf mistletoe and the mountain pine beetle. It is generally accepted that fire has played a major role in the distribution and abundance of these two damaging agents in lodgepole pine forests (Amman, 1975; Alexander and Hawksworth, 1975, 1976; and Amman and Cole, 1983). Certainly large, extensive stands of pure lodgepole pine regeneration are relatively free of these agents for decades following severe wildfires (Lotan 1975a; Lotan, 1976), but these same areas will become susceptible as they mature. The use of fire and/or harvesting techniques can influence the impact of pests.

Dwarf Mistletoe

Fire may enhance or disrupt the population of dwarf mistletoe, depending upon current situations and the nature of the fire (Alexander and Hawksworth, 1975). Widespread, stand-destroying fires have a sanitizing effect on infested stands, whereas surface fires or fire burning in a mosaic pattern leave infested trees that lead to further spread of dwarf mistletoe. Wildfire has probably served as a natural check on dwarf mistletoe populations. On the other hand, tree mortality, spike tops, witches' brooms, and resin exudation increase fuels (Beaufait, 1971) and result in greater incidence and intensity of fire. Overall, the decrease in area burned as a result of fire control may have led to an increase in dwarf-mistletoe-infested stands (Kimmey, 1957; Alexander and Hawksworth, 1975; Baranyay, 1970, 1975).

Alexander and Hawksworth (1975) recommended prescribed burning as a supplement to the traditional control of dwarf mistletoe using silvicultural treatments. Prescribed fire can be used to remove groups of infested trees and may be useful where cutting is undesirable such as in wilderness or other reserve areas. Further, prescribed fire can be used in combination with silvicultural treatment. Kimmey and Graham (1960) recommended using broadcast burning to kill unmerchantable trees following clearcutting. The potential for using prescribed fire to reduce the incidence of dwarf mistletoe is great. What is needed is quantitative information for developing prescriptions to meet the desired end.

Mountain Pine Beetle

The mountain pine beetle is the most serious insect pest in lodgepole pine forests. About every 20 to 40 years epidemics sweep through lodgepole pine forests and seriously affect the sustained yield and regulation of managed forests (Wellner, 1978). During these epidemics the beetle kills almost all merchantable trees, which complicates the management of the species. Even in unmanaged forests the beetle kills trees over entire hillsides or canyons, arousing public concern. In addition, reserve areas such as wilderness and parks may become the source of infestation for adjacent managed areas. Further, the fuel that is created by beetle-killed trees creates a serious fire hazard.

Past efforts of direct chemical control have proven futile (Amman and Baker, 1972). The beetles simply multiplied faster than areas could be treated. Thus current strategies for control of the beetle involve breaking up the large stands of lodgepole pine by an admixture of age classes and alternate tree species (Roe and Amman, 1970; Amman and Baker, 1972; Cole, D. M., 1978; Cole, W. E., 1978). D. M. Cole (1978) suggested several strategies to accomplish this, including the use of fire (fig. 6). Unfortunately, as in the case of controlling dwarf mistletoe, quantitative relationships of fire and the beetle have not been established. There is much research to be conducted. In the meantime, we know that establishing a new stand will curtail beetle populations because mountain pine beetles are not active in young, small diameter trees. We also know that beetle epidemics created large amounts of jack-strawed fuel that often results in large, extensive fires (Lotan 1976).
Program to control losses to the MPB in lodgepole pine forests

Commercial forest strategy

Prevention tactics

Increase mortality of beetle

Direct
  -Insecticides
  -Trapping (Pheromones)

Indirect
  -Biotic limiters
  *-Sanitation cutting (Partial cutting)

Silvicultural manipulation
  *-Genetic resistance
  *-Block cutting to gain age-size diversity of stands
  *-Stocking, size, vigor, and rotation control
  *-Manipulate species composition
  *-Prescribed fire

Increase resistance of stands

Utilization tactics

*Salvage cutting after mortality
*Sanitation cutting before mortality (partial cutting)

*Manage natural fire
*Prescribed fire

Noncommercial forest strategy

Amelioration Tactics

*Manage natural fire

Figure 6.—Role of silvicultural practices and prescribed fire for controlling losses to mountain pine beetle.
**LITERATURE CITED**

Ackerman, R. F. 1957. The effect of various seedbed treatments on the germination and survival of white spruce and lodgepole pine seedlings. Canadian Department of Northern Affairs and Natural Resources Forestry Research Division Technical Note 63, 23 p. Ottawa, Canada.

Adams, David L. 1972. Natural regeneration following four treatments of slash on clearcut areas of lodgepole pine—a case history. University of Idaho, College of Forestry, Wildlife, and Range Sciences Experiment Station Note No. 19, 2 p.


Barrows, Jack S. 1951. Forest fires in the northern Rocky Mountains. USDA Forest Service Station Paper No. 28, 251 p. Northern Rocky Mountain Forest and Range Experiment Station, Missoula, MT.


Brown, James K. 1974. Reducing fire potential in lodgepole pine by increasing timber utilization. USDA Forest Service Research Note INT-181, 6 p. Intermountain Forest and Range Experiment Station, Ogden, UT.


Horton, K. W., 1953. Causes of variation in stocking of lodgepole pine regeneration following fire. Canadian Department of Northern Affairs and Natural Resources Forestry Research Division Silvicultural Research Leaflet 95, 5 p. Ottawa, Ontario, Canada.


Kimmey, J. W. and Donald P. Graham. 1960. Dwarf mistletoes of the Intermountain and Northern Rocky Mountain Regions and suggestions for control. USDA Forest Service Research Paper 60, 19 p. Intermountain Forest and Range Experiment Station, Ogden, UT.


Lawson, Bruce D. 1973. Fire behavior in lodgepole pine stands related to the Canadian fire weather index. Canadian Forestry Service, Pacific Forest Research Centre, Victoria, B.C.


Lotan, James E. 1964a. Initial germination and survival of lodgepole pine on prepared seedbeds. USDA Forest Service Research Note INT-29, 8 p. Intermountain Forest and Range Experiment Station, Ogden, UT.


Lotan, James E. and David A. Perry. 1977b. Fifth-year: seedling ratios of lodgepole pine by habitat type and seedbed preparation technique. USDA Forest Service Research Note INT-239, 6 p. Intermountain Forest and Range Experiment Station, Ogden, UT.


Lyman, C. K. 1945. Principles of fuel reduction for the Northern Rocky Mountain Region. USDA Forest Service Progress Report 1, 98 p. Northern Rocky Mountain Forest and Range Experiment Station, Missoula, MT.

Lyon, L. Jack. 1977. Attrition of lodgepole pine snags on the Sleeping Child Burn, Montana. USDA Forest Service Research Note INT-219, 4 p. Intermountain Forest and Range Experiment Station, Ogden, UT.


Minore, Don. 1968. Effects of artificial flooding on seedling survival and growth of six northwestern tree species. USDA Forest Service Research Note PNW-92, 12 p. Pacific Northwest Forest and Range Experiment Station, Portland, OR.


Noble, D. L. 1979. Roots of lodgepole pine seedlings reach depth of only 3 to 4 inches their first season. USDA Forest Service Research Note RM-363, 3 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.


Technical Report INT-132, 58 p. Intermountain Forest and Range Experiment Station, Ogden, UT.


Shearer, Raymond C. 1975. Seedbed characteristics in western larch forests after prescribed burning. USDA Forest Service Research Paper INT-167, 26 p. Intermountain Forest and Range Experiment Station, Ogden, UT.


Tackle, David. 1956. Stocking and seedbed distribution on clear-cut lodgepole pine areas in Utah. USDA Forest Service Research Note 38, 3 p. Intermountain Forest and Range Experiment Station, Ogden, UT.


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LODGEPOLE PINE
THE SPECIES AND ITS MANAGEMENT

SYMPOSIUM PROCEEDINGS

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