Steven G. Whisenant

Chapter 11

Vegetative Manipulation with Prescribed Burning

Introduction

Plant responses to fire differ because of phenological variations at the time of burning, inherently different susceptibilities to heat damage, differing regenerative abilities, and different responses to the postfire environment. Individual plants of the same or different species may have different responses to fire because of local variations in fire temperature or microenvironment. The postfire assemblage of plants may have few species changes, as is often the case after grassland fires, or may be dramatically different in both species composition and structure, following some forest fires. When understood, these differential susceptibilities to fire can be used to manipulate plant communities. Prescribed burning can often be used to enhance one species or assemblage of species while reducing another species or assemblage of species (fig. 1).

Figure 1—Prescribed fire in a spruce-fir-aspen stand. Fire is used to suppress or remove spruce and fir and to release aspen and understory herbs.

Most plants have some tolerance to fire, yet undesirable results can occur. These undesirable results can be minimized if the resource manager has an understanding of fire ecology and prescribes a fire under conditions adequate to accomplish management objectives. Tables 1 and 2 summarize the effects of fire on some grasses and shrubs common to the Intermountain area. These should be used as approximations of the expected results, which are subject to variation.

Prescribed burning can be a useful tool in both big sagebrush and juniper-pinyon communities if burning is carefully prescribed and the area is deferred from livestock grazing for 2 years after treatment (Wright and others 1979).

Fire, improperly used (or wildfires), may have such adverse effects as converting desirable shrub (fig. 2) and perennial grass stands to annual grasses or maintaining annual grass communities. Understanding how fire affects plants is an important step in being able to use fire to accomplish specific management objectives. The effects of fire on plants can be clearly understood only if the modes of action of fire on that community are considered. According to Lloyd (1972) the primary effects of fire on plant communities are: (1) the direct action of heat on plants and soils, (2) changes in the microenvironment, and (3) the redistribution of certain nutrients. The first of these involves breakdown of organic compounds, possible stimuli to dormant organs, and physical, chemical, and biotic changes in the surface soil. The second mode of action affects the microclimate, and the third includes losses of volatile compounds in the smoke and deposition of nonvolatile compounds in the ash. Understanding these three modes of action is helpful in understanding how fire can be used to accomplish management objectives.

Table 1—Summary of fire effects on some grasses of the Intermountain Region[a].

Species	Response to fire	Remarks
Cheatgrass	Undamaged	Reduction in cheatgrass usually results from seed consumption and changes in the microenvironment caused by fire. Recovers in 1 to 2 years
Bluegrass	Slight damage	Slight reductions following late summer and fall burning
Idaho fescue	Slight to severe damage	Greatly damaged by summer burning. Burning in spring or fall, under mild conditions and good soil and water, causes little damage
Indian ricegrass	Slight damage	Tolerant of fire, but may respond slowly to improved conditions
Needlegrass	Moderate to severe damage	Needlegrass are among the least fire resistant bunchgrasses. Large bunchgrasses. Large plants are damaged more than small plants. A 50 percent reduction in basal area is possible
Plains reedgrass	Undamaged	Rhizomatous species that is very tolerant of fire
Bottlebrush squirreltail	Slight damage	One of the most fire resistant bunchgrasses. Often increases for 2 to 3 years after burning. Can be damaged by severe fires in dry years
Wheatgrass	Little or no damage	Bluebunch wheatgrass can be damaged if burning occurs in a dry year. Other wheatgrass, particularly crested wheatgrass are difficult to burn in seeded monocultures
Prairie junegrass	Undamaged	Often increases its density following burning

[a]Adapted and modified from Wright and others (1979).

Table 2—Summary of fire effects on some shrubs of the Intermountain Region[a].

Species	Response to fire	Remarks
Antelope bitterbrush	Variable, slight to severe	Decumbent forms sprout more readily than the columnar forms. Subsequent seedling establishment is higher on more mesic sites. Spring and late fall burning is less damaging than summer burning (Bunting and others 1985)
Sagebrush species	Slight to severe	Black sagebrush and low sagebrush are small and widely spaced. They are rarely burned and may often be used as fire breaks when burning adjacent big sagebrush. Silver sagebrush is capable of sprouting after being burned, and is only slightly damaged. Big sagebrush is killed when burned
Rabbitbrush	Usually enhanced	Vigorous sprouter that often increases following burning
Horsebrush	Stimulated	Vigorous sprouter that may greatly increase following burning
Gambel oak	Stimulated	Vigorous sprouter with rapid regrowth following burning
Snowberry	No lasting damage	Vigorous sprouter that may be enhanced by low severity fires or damaged by high severity fires
Curlleaf mountain mahogany	Variable	Mature, decadent stands, with curlleaf mountain mahogany mostly in excess of 50 years old may be rejuvenated by fire. Also may be beneficial when conifers are out competing mahogany seedlings. Damaging to younger, vigorous stands (Gruell and others 1985)

[a]Adapted and modified from Wright and others (1979).

Heat damage is a function of duration of exposure, environmental temperature, and the initial vegetation temperature (Hare 1961). The quantity of heat required to raise the temperature of living vegetation to the lethal temperature is directly proportional to the difference between the lethal temperature and the initial vegetation temperature. Initial vegetation temperature is a function of air temperature and availability of radiant energy, both are largely regulated by the time of day and season of year. The physiological condition of the protoplasm is an important variable regulating heat effects on plants. As the moisture content of vegetative tissue decreases, its tolerance to heat increases because of the high specific heat of water and the physiological activity of hydrated tissues (Hare 1961).

Figure 2—Wildfire in Wyoming big sagebrush and winterfat communities. Within 2 years following fire, the areas were completely dominated by cheatgrass.

Burning herbaceous plants during periods of active growth generally has adverse impacts on the plant. Conversely, dormant plants are seldom seriously damaged by burning. For example, burning in the spring usually increases warm season herbaceous plants while damaging cool season herbaceous plants (Daubenmire 1968; Wright and Bailey 1982). Burning in the fall usually has the opposite effect.

Plant growth form is a critical factor in the response of plants to heat, with rhizomatous plants having the greatest degree of protection. In general, the deeper the rhizomes are located in the soil, the greater the survival rate from fire (Flinn and Wein 1977). Fire may have either beneficial or detrimental effects on annual plants, depending upon the growth stage, location of the seeds during the fire (Daubenmire 1968), and the resulting microenvironment (Evans and Young 1984). The heat generated by a fire may be sufficiently high to kill seeds in the upper part of the surface litter, or in the inflorescence, but seeds on or under the mineral soil surface often survive (Bentley and Fenner 1958; Daubenmire 1968). Understanding the effects of fire on the various plant life forms is a critical component in prescribing the use of fire to effect desired changes in a plant community.

Season of burning, which greatly influences initial vegetation temperature, tissue hydration, phenology, and position of perennating buds is extremely important in regulating the effects of fire. Within a season, fire intensity increases with increasing fuel, ambient temperature, windspeed, decreasing fuel moisture, and relative humidity. Thus, by carefully selecting the burning time and environmental conditions, a resource manager can control fire intensity and damage to the existing plant community.

Woody plants may be well insulated from extreme temperatures by bark. Fahnestock and Hare (1964) reported longleaf pine bark surface temperatures, during burning, varied from 554 to 1,472 °F (290 to 800 °C) while cambial temperatures varied from 100 to 180 °F (38 to 82 °C). Seedlings of many plants are more susceptible to fire damage than mature plants. Young ponderosa pine and honey mesquite are much more likely to be killed by fire than older plants (Wright and Bailey 1982). Much of this increased protection may be due to the increased bark thickness on older plants.

Considerable research on the effects of litter removal in grassland plant communities has demonstrated the importance of that aspect of grassland fire ecology (Dix 1960; Hulbert 1969; Lloyd 1972; Old 1969). The mechanical removal of dormant, standing herbaceous vegetation, and mulch often accomplishes the same results on perennial plants as burning. Heavy mulch accumulations produce a dominating cover that stifles growth by depriving the plants of space and light (Dix 1960; Old 1969; Scifres and Kelley 1979; Vogl 1974; Whisenant and others 1984). Chemical substances leached from undecomposed plant material may further inhibit growth (Rice 1974).

Postburn responses of grasses in arid and semiarid regions are largely influenced by soil water content after burning. When prescribed fires are followed by a prolonged dry season, the vegetation response is predictably poor. Burning only when soil water content is high is the most reliable way to ensure adequate water for regrowth of plants in regions with unreliable rainfall (Wright 1974).

The importance of postburn changes in soil chemistry has been widely investigated. Most reports from grasslands indicate that nutrient gain from ash is of no detectable significance; any increases in production are a result of litter removal (Hulbert 1969; Lloyd 1971, 1972; Old 1969). In forests, where great volumes of plant material may be consumed, the ash may serve as an important fertilizer (Chandler and others 1983). Soil pH of acidic, weakly buffered forest soils is usually raised following fires that consume great quantities of woody material (Ahlgren and Ahlgren 1960). Most soils of western rangelands are basic, and strongly buffered.

The current uses of prescribed fire on western wildlands may be categorized into four interrelated areas: (1) maintaining existing vegetation, (2) site preparation prior to revegetation, (3) reducing woody plant density, and (4) wildlife habitat improvement.

Maintaining Existing Vegetation

Prescribed fires used for maintenance of existing vegetation are relatively cool fires. They maintain a desirable balance in the vegetation (Scifres 1980) and do not create major changes in the vegetation community. Maintenance fires are usually conducted during relatively cool weather with a higher relative humidity than fires used to create type changes or remove woody debris.

Grass (Christensen 1977; Daubenmire 1968; Lloyd 1971) and browse (DeWitt and Derby 1955; Dills 1970; Lay 1957) appearing after a fire may be attractive to grazing animals and often results in higher weight gains (Anderson and others 1970; Daubenmire 1968). Following prescribed burning, plants are often higher in crude protein, ether extract, nitrogen free extract, digestible energy, phosphorus, nitrogen, and potassium (Daubenmire 1968; DeWitt and Derby 1955; Lay 1957, Lloyd 1971). Most studies report that cattle make greater weight gains on burned than on unburned areas (Anderson and others 1970; Duvall and Whitaker 1964). These increases in nutrient content are often limited to 3 to 4 months after burning. Many of the increases in plant nutritive quality can be explained by the reduced tissue age of plants in recently burned areas (Christensen 1977).

Increases or decreases in forage quality or productivity may be determined by the season of burning. For example, late spring burning of big bluestem grassland in Kansas increased protein content, whereas burning at other seasons decreased it (Aldous 1934). Where fire alters dry matter production per unit of land surface (or per plant), the gains or losses expressed as a percentage of dry matter may be reversed when expressed on a land area basis. Thus, the percentage protein in the shoots of certain Australian grasses was higher after a fire, but the stand of grass was thinned so much that there was much less total protein on a land area basis (Smith and others 1960). In contrast, Christensen (1977) stated that because of increased net production in the burned area, uptake of all nutrients on a unit area basis by plants in the burned area undoubtedly exceeded uptake in unburned areas despite the lack of significant differences in tissue content of certain nutrients.

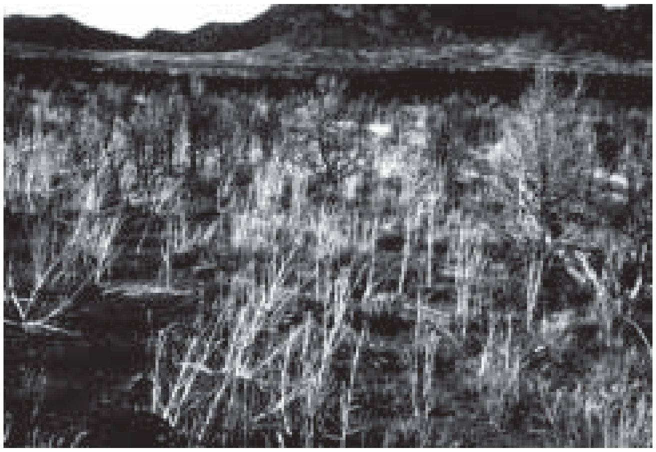

Figure 3—Effect of prescribed fire on small pinyon trees and understory herbs 2 years following fire. This 27-year-old chaining project is primarily on year-round range.

Sites in the early stages of reinvasion by big sagebrush, pinyon (fig. 3), juniper or other shrubs that may be considered undesirable in excessive amounts, are one of the best uses of prescribed burning. Ideally, the burning occurs while there is still sufficient herbaceous fuel available (fig. 4) and the woody plants are small and most susceptible to fire-caused mortality. Seedlings of woody plants are more susceptible to fire damage than mature plants. Small plants of juniper and pinyon species are usually more easily killed by fire, because the foliage is more likely to be ignited by ground fires (fig. 3). Mature pinyon or juniper trees often exhibit a greater distance between the ground and the lowest foliage, particularly when plants are heavily foraged, or high-lined, by big game animals. Fire in the herbaceous layer may pass under mature pinyon or juniper trees without igniting the canopy.

Site Preparation Prior to Revegetation

Prescribed burning may have several potential uses in the revegetation of western wildlands. Herbicide treatments or chaining may create debris that interfere with activities of livestock, wildlife, or planting equipment. Fire may be used to reduce this woody debris (fig. 5). The effectiveness of fire in debris removal varies with environmental conditions and the amount and distribution of fuel. Burning conditions favorable for debris removal are more hazardous than burning conditions used for maintenance burning. Ignition and consumption of woody debris requires hotter, drier environmental conditions. Certain detrimental effects on desirable species may also be associated with this intensity of burning. The potential damage to desirable species should always be carefully weighed against the expected benefits from burning to consume woody debris.

Competition from herbaceous weeds is one of the most important causes of seeding failures and the degeneration of established seedings. Direct seeding efforts may be damaged by competition from annual grasses. Cheatgrass has invaded big sagebrush communities in much of the Western United States (Evans and Young 1975b). Cheatgrass is highly competitive with perennial grasses and once established, may continue to dominate the site (Young and Evans 1973). Daubenmire (1968) stated there was no conclusive evidence that cheatgrass will relinquish an area to indigenous species once it becomes established

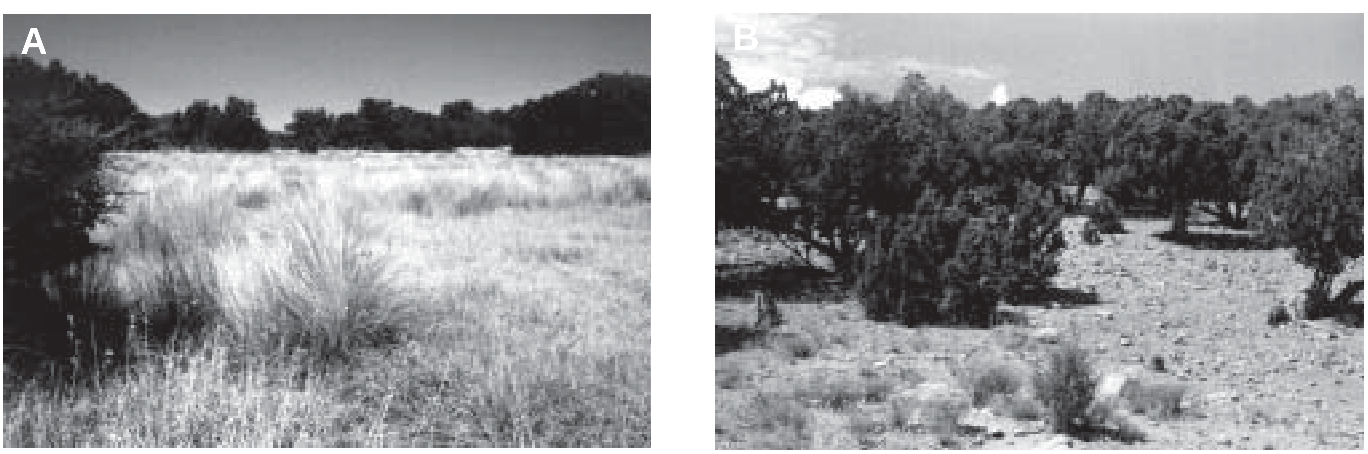

Figure 4—(A) Sufficient fuel has to be available to successfully burn juniper-pinyon stands. (B) Fire cannot be started or continued when understory fuel is lacking.

Figure 5—Prescribed fire being used to reduce woody debris on a chained juniper-pinyon area used by cattle, elk, and mule deer.

(fig. 6). The highly competitive nature of cheatgrass makes establishment of desirable perennial grasses very difficult. In a Nevada study, growth of perennial grass seedlings was dependent upon cheatgrass control (Evans and others 1970). Without cheatgrass control, soil water was depleted prior to establishment of perennial grasses.

Fire has been used with varying degrees of success in big sagebrush-cheatgrass communities to prepare the area for seeding to perennial grasses. It has not been very successful where cheatgrass is dominant (Wright and others 1979). Procedures developed for rehabilitating cheatgrass-dominated rangeland following wildfires may also be used following prescribed burning. Areas dominated by cheatgrass may be treated with atrazine or plowed and seeded to aid establishment of an adequate stand of perennial grasses (Eckert and Evans 1967; Eckert and others 1974).

Fire may be used to convert juniper-pinyon communities to a more desirable mixture of woody and herbaceous plants (fig. 3). Simply removing the trees does not ensure that the resulting vegetation mixture will be dominated by more desirable herbaceous and woody plants. Removing woody plants often results in increased cheatgrass densities. The vegetation resulting from disturbing western juniper woodlands may be considered as a greater environmental degradation than tree invasion if sustained forage production is used as the evaluation criteria (Young and others 1985). They discussed obstacles encountered in attempting to revegetate western juniper-dominated rangelands. The aerial standing crop of the trees often reaches 187 tons per acre (419 metric tons per ha). This represents a great sink of nutrients that are unavailable for plant growth and can become an impediment to seeding equipment. A flush of annual weeds usually occurs following tree removal, which may reduce establishment of seeded species. Some type of weed control is recommended following tree removal, with herbicides providing the most potential (Young and others 1985).

Big sagebrush-cheatgrass communities (fig. 7) can be successfully seeded following burning if the fire is hot enough to consume both sagebrush plants and cheatgrass seeds in the standing inflorescence (Young and others 1976b). Density and ground cover of cheatgrass may be drastically reduced the first year after fire but increase dramatically the second year. In one study there were less than 0.9 plants per ft^2 (10 plants per m^2) the first year after fire, nearly 740 plants per ft^2 (8,000 plants per m^2) the second year, and more than 1,490 plants per ft^2 (16,000 plants per m^2) the third year (Young and Evans 1978b). Ground cover of cheatgrass was about 2 percent the first year, 12 percent the second, and 14 percent the third year after burning.

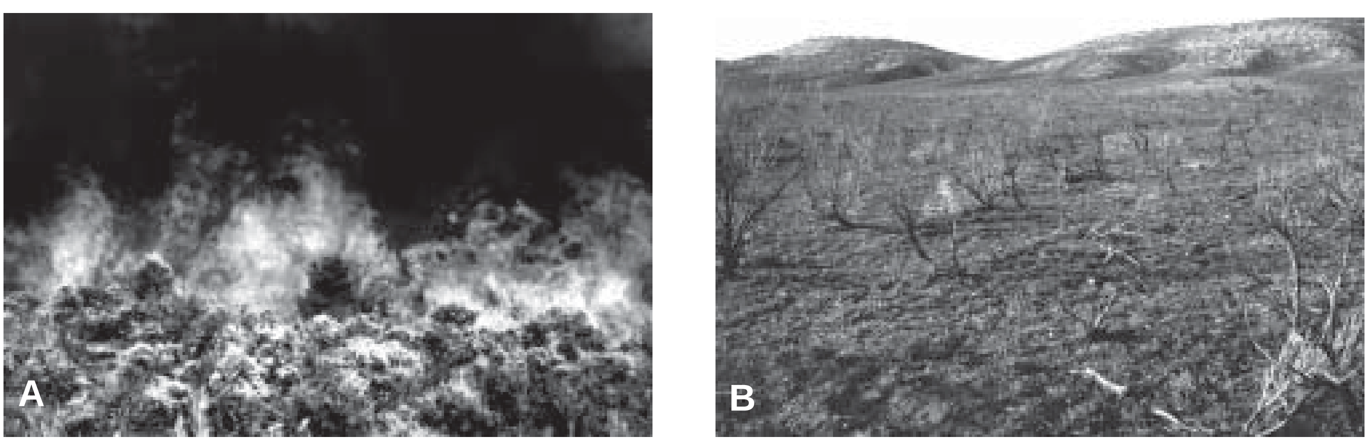

Figure 6—Fire in a big sagebrush-perennial grass-cheatgrass community (A) provided the established perennial grasses the opportunity to once again become dominant (B).

Figure 7—Big sagebrush community with sufficient understory to burn. Seeding of desirable perennial species should occur following the burn.

Much of the postburn area provides a nutrient-rich environment, allowing full expression of downy brome's growth potential (Young and Evans 1978b). Even though much of the cheatgrass seed is destroyed by fire, some survive and develop into large vigorous plants with many tillers and seeds produced per plant. Young and Evans (1978b) found cheatgrass seed production per plant in an unburned area varied from less than 10 to 250 per plant while in a burned area it varied from 960 to almost 6,000 per plant. They attributed this response to reduced intraspecific competition resulting, from lower plant density. Hassan and West (1986) found that even though fire reduced cheatgrass seed pools by half, the seed pool increased within 1 year to twice the level on unburned areas. If much cheatgrass seed remains, the area may be chemically fallowed (Eckert and Evans 1967), or the cheatgrass seedlings plowed prior to seeding perennial grasses.

After fire there is a dramatic reduction in diversity of annual plants. Wildfires are a major agent for increases in cheatgrass, which is well suited to postburn conditions because of its reproductive and competitive abilities (Evans and Young 1984). Rehabilitation of big sagebrush-cheatgrass rangeland following wildfires has resulted in the conversion of large areas from annual grass to perennial grass dominance (fig. 6). Wildfires in this vegetation type may be either extremely detrimental or beneficial, depending on rehabilitation efforts. The advantages obtained by burning must be realized during the first year following the fire.

An accumulation of plant litter on the soil surface is an important requirement for establishment of cheatgrass in the arid Intermountain area (Evans and Young 1970). Plant litter on the soil surface moderates the microenvironmental parameters of air temperature and available water in the surface soil. This creates a seedbed environment within the physiological requirements for cheatgrass seed germination and seedling growth. The microenvironment of a bare soil seedbed does not permit germination and establishment of cheatgrass in Nevada (Evans and Young 1970). However, there is some evidence, but little data, to indicate that plant litter on the soil surface is less critical for cheatgrass seedling success in more mesic regions of the Western United States.

Planning revegetation efforts requires that potential cheatgrass competition levels be predicted. Using a bioassay technique, Young and others (1976b), determined the density of viable cheatgrass seeds relative to postfire seedbed conditions. By determining the relative cover of ash and unburned organic matter after fire, an estimate of the potential cheatgrass reinfestation can be determined. Bioassays from the area to be rehabilitated may be conducted by placing samples of unburned organic matter and ash in small cups and covering with vermiculite (Young and others 1969a). Cheatgrass seedlings from the samples are counted for 8 weeks and calculated on a number per m^2 basis. As few as 4.0 seedlings per ft^2 (43 cheatgrass seedlings per m^2) moderately reduced establishment of crested wheatgrass seedlings and 64.0 seedlings per ft^2 (688 cheatgrass seedlings per m^2) prevented perennial grass seedling establishment in a greenhouse (Evans 1961).

Effects of Fire on Woody Plants

Management goals for sagebrush wildlands vary, but conservation of the basic natural resources, soil and vegetation, is usually one of the primary considerations. Blaisdell and others (1982) stated that in general, there is too much sagebrush and other low value shrubs, too many annuals, and not enough perennial grasses and forbs. Under these conditions, the most common vegetation management goal is to reduce sagebrush and increase perennial grasses and forbs.

Grazing management may be used to improve the vegetation if deterioration has not progressed too far. Unfortunately, the aggressive, long lived nature of sagebrush often requires some form of direct control followed by revegetation with perennial, herbaceous species to restore the area to a satisfactory condition (Blaisdell and others 1982). It is wise, however, to consider the desirable attributes of sagebrush, in proper amounts, when planning control measures. Sagebrush is a part of many native plant communities and has many benefits when not overly abundant. Regardless of the control measure used, proper grazing management should always be part of the long-term management plan.

Figure 8—Release of understory herbs and resprouting of aspen following prescribed burn.

Figure 9—Response of understory grasses and forbs following burning of lodgepole pine.

Forage that is unavailable to the browsing animal is of little value to them. Many woody plants obtain a height that places all the yearly leaf and shoot production out of reach of most browsing animals. Aspen and bitterbrush are just two of the plants capable of reaching that height. When plants resprout following top removal, the opportunity exists to increase forage availability with fire. Fire may stimulate suckering or resprouting of some species; placing the majority of annual browse production within reach of most animals. When aspen is clearcut, burned, or otherwise disturbed, resprout (sucker) density may be in the tens of thousands per acre (fig. 8) (Jones 1975). Maximum densities are reached the first year and begin to decline after that (Jones and Trujillo 1975). Forage production in aspen and conifer (fig. 9) communities is greatly increased following burning (Bartos and Mueggler 1979; Jones 1975).

Juniper and pinyon species have invaded many sagebrush/grass and grass communities during the past 80 years and have also increased their density over much of their range. The highly competitive nature of these trees has proven detrimental to some of the more desirable woody and herbaceous species. Several studies have attributed this increased density to overgrazing and reductions in fire frequency, which have enabled these fire intolerant species to increase both their range and density (Blackburn and Tueller 1970; Johnsen 1962).

In the sagebrush and juniper-pinyon communities the primary use of prescribed burning has been to reduce competition between the excessive woody plant cover and the more desirable plant species (fig. 10). Burning these communities often increases productivity, quality, and palatability of herbaceous plants and may have long lasting effects on the vegetative composition. Evans and Young (1978) stated that establishment of perennial grasses was an important factor in delaying the reinvasion of big sagebrush and low rabbitbrush.

Bitterbrush exhibits a less predictable response to fire. Several factors are undoubtedly responsible for this variability; not the least of which is the difference between wildfires, which often occur during the hottest period of the year, and prescribed fires that are often set during cooler weather. Wildfires usually occur during the summer, when carbohydrate reserves are low (Menke and Trlica 1981). Wildfires have reportedly destroyed bitterbrush on large areas (Hormay 1943) and "permanently eradicated" it on many sites in the Great Basin (Billings 1952). Bitterbrush resprouted frequently, but inversely with fire intensity following fires in eastern Idaho (Blaisdell 1950, 1953). Resprouting was limited following wildfires in Washington (Daubenmire 1970) and California (Nord 1965). Other research that included prescribed fires, concluded that burning in the spring was less

Figure 10—Increase of native grasses, forbs, and palatable shrubs following wildfire in a juniper-pinyon community.

damaging than burning at other times (Blaisdell and Mueggler 1956).

Genetic traits account for some of the variable response of bitterbrush to fire (Bunting and others 1985; Clark and others 1982; Giunta and others 1978). Decumbent forms resprout more frequently than erect forms of bitterbrush, particularly following spring burns (Bunting and others 1985; Clark and others 1982). Clark and others (1982) stated that bitterbrush does not sprout abundantly after fire. However, fire creates litter-free sites necessary for germination of rodent-cached seed (Sherman and Chilcote 1972). Bunting and others (1985) studied bitterbrush response, 3 to 10 years after burning, following both prescribed fires and wildfires at 56 locations in Idaho and Montana. They found seedling establishment rates were greatly influenced by soil water content; more mesic sites had higher bitterbrush establishment rates. Since most bitterbrush reproduction is from seed (Daubenmire and Daubenmire 1968; West 1968) rather than vegetatively, burning may enhance reproduction in a few situations (Clark and others 1982).

Use of Fire to Improve Wildlife Habitat

Leopold (1933) defined game management as "…the art of making land produce sustained annual crops of wild game for recreational use." Burger (1979) defined wildlife management as "…a blending of science and art, aimed at achieving sound human goals for wildlife resources by working with habitats, wildlife populations, and people." Others definitions exist, but like these, virtually all of them place some emphasis on managing the land as habitat. Management of habitats and wildlife populations are closely linked (Scotter 1980). Wildlife habitat is a constantly changing entity that cannot be preserved unchanged. It consists principally of vegetation, and as such is subject to change through succession.

Fire serves as a primary agent of successional setback in many communities. In moist environments, marginal burning conditions reduce fire frequency (Wright and Bailey 1982). A coincidence of fuel buildup, extreme burning conditions, and ignition eventually result in intense fires that may burn large areas. Even under these circumstances, there are areas within the fire's boundaries which, because of aspect, additional moisture, type or amount of vegetation, do not burn or burn incompletely. Along the edges of most fires there is mixing of burned and unburned areas. "Fingers" and pockets of unburned or incompletely burned habitat remain in and around the burned areas (fig. 11).

Improved fire protection has contributed to the decreased quality of some wildlife habitat by aiding succession to plant communities with low capacities to support certain species of animals (particularly big game animals) (Scotter 1980). Prior to human's intervention, wildfires regularly burned large areas. Much of the postfire vegetation provided favorable forage for livestock and certain game species, especially deer and elk (Lyon 1966b). For example, in the Northern Region of the U.S. Forest Service, which includes portions of Idaho, Montana, and Wyoming, the area burned by wildfire declined from an annual average of 249,000 acres (101,000 ha) at the turn of the century to less than 4,942 acres (2,000 ha) in the early 1960's (Pengelly 1966). This resulted in an increase in the amount of mature forests at the expense of the grass or shrub subclimax vegetation. These succession patterns are common to much of Western North America, and have reduced the quality and extent of large herbivore habitat (Scotter 1980).

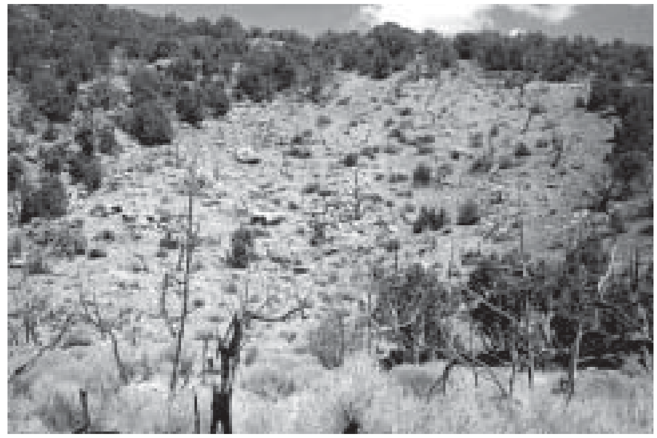

Figure 11—Fire can occur in pockets or fingers, thus increasing community diversity and edge areas.

Prescribed burning is a promising tool for wildlife habitat improvement. It has been used to enhance habitat diversity, and to improve forage quality and quantity (fig. 1, 9, 10, 11) Severson and Medina (1983) stated "…prescribed burning can be used to improve or create wildlife habitat by creating diversity and edge and by improving the quantity and quality of food. Diversity and edge enhancement is generally accomplished by eliminating overstory vegetation, trees and shrubs, in prearranged patterns that create optimum cover/forage ratios. Benefits to food resources can be realized by eliminating undesirable plants, removing dense, rank, and/or overmature growth to stimulate crown or root sprouting, and increasing the nutritive value."

Fire, like any other management tool, is not a panacea. The misapplication of fire can have devastating effects on wildlife habitat (fig. 12). Understanding the

Figure 12—Misuse and uncontrolled use of fire can result in losses of critical wildlife habitat. This fire destroyed prime sage-grouse and mule deer habitat.

influence of fire on plant succession and the relationships between animal habitat requirements and plant succession will enable resource managers to make informed decisions.

Successional Relationships Between Plants and Animals

Many animals are associated with one or more of the successional stages or plant communities. Bailey (1984) classified animals into three categories that describe the relationships between their habitat requirements and plant succession. He considered animals as either climax-adapted (Class I), adapted to early successional stages (Class II), or adapted to a mixture of successional stages (Class III). By understanding these relationships the resource manager can often use fire to retard or set back succession to a vegetative type more compatible with management objectives.

Animals have different degrees of versatility in the number of plant communities and successional stages that they can use for feeding and reproduction. Populations of climax-adapted species (Class I) may be adversely affected by habitat disturbances, such as fire. Bailey (1984) listed the woodland caribou, spruce grouse, snowshoe hare, and pileated woodpecker as examples of climax-adapted species. These types of animals are poorly equipped to adapt to habitat changes and are best managed by protecting their habitat.

Class II species are typified by the bobwhite quail, cottontail rabbit, and Swainson's thrush (Bailey 1984). Periodic habitat disturbances, such as fire, maintain plant successional stages most favorable to Class II species.

Animals that can adapt to a mixture of successional stages (Class III species) are less affected by abrupt habitat changes. Bailey (1984) considered ruffed grouse, whitetailed deer, and mule deer to be good examples of Class III species; which may require disturbance or protection, depending on which habitat component is limiting.

Thomas (1979) developed a versatility index (V) that can be used to rate individual animal species, or all the species of an area. The V score for each species is derived by determining the total number of plant communities and the total number of successional stages to which the species shows primary orientation for feeding and reproduction: $V = (Cr + Sr) + (Cf + Sf)$ where V is the versatility score, Cr is the number of communities used by the species for reproduction, Sr is the number of successional stages used for reproduction, Cf is the number of communities used for feeding, and Sf is the number of stages used for feeding (Thomas 1979). The versatility index is a tool that allows wildlife habitat managers to estimate how many, and which wildlife species are likely to benefit or be harmed by prescribed fire in a specific area.

Wildlife habitats should be identified in such a way that they can be considered simultaneously with other land management activities. This can be accomplished by equating plant communities and successional stages with habitats for wildlife (Thomas 1979). Associating individual wildlife species or groups of species with plant communities and stages of plant succession allows the wildlife manager to translate range and forest inventories into wildlife habitat information (Whisenant 1986a).

Prescribed burning has been successfully used to increase willow abundance for moose habitat improvement. Geyer's willow is a subclimax species, highly preferred by moose, which is replaced by spruce through succession. Prescribed burning has been used in western Wyoming to prevent succession to spruce, and to stimulate willow regeneration (Weiss 1983). The resulting increase in amount of willow was followed by increased moose use of the burned areas.

Cover Requirements

Scotter (1980) asserted that habitat components such as type and amount of cover may be equally as important as quantity and quality of food.

The primary function of cover is to provide escape routes and hiding places from predators, in addition to shelter from weather (Black and others 1976; Severson and Medina 1983; Thomas 1979; Thomas and others 1976). Hiding cover provides the security that makes an animal's use of the area possible, and thermal cover helps the animal maintain body temperatures within tolerable limits.

Requirements for hiding cover vary throughout the year. Leopold (1933) listed five kinds of cover for birds: winter cover, refuge cover, loafing cover, nesting, and roosting cover. There is much overlap between these kinds of cover; one location may serve as adequate winter, refuge, and nesting or loafing cover. Rarely are cover requirements for a particular species completely understood. Careful consideration of these requirements with respect to the location and species in question will help to alleviate many of the potential problems.

For example, hiding cover for elk has been defined as the vegetation capable of hiding 90 percent of an elk from the view of a person at 200 ft (61.0 m) or less (Black and others 1976; Thomas 1979). The amount of vegetation required to do this varies between vegetation type and location. Elk use of cover is significantly reduced beyond 900 ft (274.3 m) from an opening (Reynolds 1966). Hiding cover that meets the requirements for elk will be more than adequate for deer (Black and others 1976).

For elk management, an optimum ratio of 40 percent cover to 60 percent foraging area has been recommended (Black and others 1976; Thomas 1979). This suggestion was based on how elk used cover and openings in relation to edges. The 60 percent forage area included all openings and forested areas that did not qualify as cover.

Thomas and others (1976) defined thermal cover for elk as a stand of coniferous trees in excess of 40 ft (12.2 m) tall with a canopy cover in excess of 75 percent. Multilayered vegetation provides better thermal cover than single layered vegetation. At least 30 acres (12.1 ha) are required for adequate shelter from the wind, and areas larger than 60 acres (24.2 ha) are not used efficiently. Others have suggested that elk thermal cover requirements are more variable. Consistently used elk thermal cover in south-central Wyoming summer ranges are less than 5 acres (2.0 ha) in size and only 150 ft (45.7 m) from openings (Ward 1976). Thermal cover for deer has been defined (on summer and spring fall range) as trees or shrubs, at least sapling size (Black and others 1976). Deer thermal cover has an optimum size of 2 to 5 acres (0.8 to 2.0 ha) with a minimum width of 300 ft (91.4 m). Unfortunately, research into deer and elk cover requirements have rarely considered winter ranges that undoubtedly must be very important (Severson and Medina 1983).

Pronghorn antelope are associated with open country, and little research attention has been given to their thermal cover requirements. However, pronghorns are reported to make use of wind velocity barriers such as creek and river banks, road fills and dikes, and the lee sides of sagebrush (Yoakum 1980). Pronghorns have also been observed taking summer shelter under isolated trees in otherwise open valleys. Until more detailed information is available, resource managers must make subjective judgements about the adequacy of pronghorn thermal cover.

Burning may alter an animal's ability to enter an area. In forests, movements of large animals into an area may be reduced or eliminated if large numbers of fallen trees restrict movement.

Kelsall (1968) believed the tangle of dead trees on burned areas explained the observations of Banfield (1954) that barren ground caribou avoided burned forests. Gates (1968) showed that deer used burned and debris free areas more frequently than those that contained unburned logging slash. Research did not rule out the possibility that deer preferred the food on the burned areas. Where downed timber restricts movement of large ungulates into an area, the burning plan should attempt to increase animal access into as many new areas as possible or practical.

Another concept closely allied with cover is vegetation edges, which are the places where plant communities or successional stages come together (Thomas 1979). A discussion of the importance of areas of vegetation edge is aided by an understanding of two important concepts, dispersion and interspersion (Thomas 1979). The law of dispersion states "the potential density of game…requiring two or more types is, within ordinary limits, proportional to the sum of the type peripheries" (Leopold 1933). The law of interspersion states that "the number of species requiring two or more types of habitat depends on the degree of interspersion of numerous blocks of such types" (Severson and Medina 1983).

Small or patchy fires that create a mosaic of vegetation types and statures in previously homogenous vegetation are usually beneficial to most species. These types of fires not only increase the number of species present but often increase the number of individual animals. Biswell (1952) recommended small burns of 5 to 10 acres (2.0 to 4.0 ha) in a checkerboard pattern to open up dense chamise brushland for blacktailed deer, game birds, and small mammals in California. This type of burning program increased deer abundance, weight, weaning percentage, and wintering ability compared to deer from unburned areas or on large uniform burns. This improved deer performance was explained by enhanced nutritive value of plants growing in the openings.

Often it is not the quantity of the habitat components that determines animal numbers or health, but rather the degree of interspersion, or spatial relationship to other requirements (Dasmann 1964). It is the complexity of habitat requirements that leads to the recognition of the "edge effect." More edge between particular types results in greater densities of animals associated with that edge. Increasing the interspersion of types will increase the edge requirements of various animals as well as the use of diversity indices to quantify the edge (Severson and Medina 1983; Thomas 1979; Yoakum and others 1980).

Food Requirements

Nutrient contents of plants often follow a predictable annual cycle. Nutritional values are highest early in the growing season, usually decline following flowering, and are lowest during dormant periods. Most herbivores thrive as long as they can consume the young tender shoots, leaves, and buds. Nutritional difficulties occur when they are forced to eat old, coarse vegetation.

Fire can be used to remove old litter and standing vegetation from an area. This often has the effect of improving diet quality of large herbivores by reducing consumption of old coarse growth and increasing consumption of young plant parts.

The concept of tolerance ranges for all environmental factors should always be considered in any habitat analysis and improvement scheme. Dasmann (1964) aptly stated the correct approach when he wrote “the game manager, in attempts to improve habitat, must continually search through the range of potential limiting factors seeking one that can practically and economically by remedied. Habitat research and management have sometimes been defined as attempts to discover limiting factors and then to remove each in turn until the maximum feasible production of wildlife is obtained.” Unfortunately, it is not always simple to determine what is limiting wildlife populations.

Riparian Considerations

Fire can have many impacts on stream habitats. Of primary importance are changes in soil erosion, water flow, nutrient loading, and water temperature. All of these commonly increase following a fire and may be detrimental to aquatic organisms. A reduction in streamside vegetation often results from burning and is a contributing factor to many of the detrimental impacts. Sediment input to streams may reduce the area suitable for spawning or smother fish eggs with fine materials (Cordone 1961). Increased water flow may damage eggs by increasing gravel movement (Lyon and others 1978). Removal of streamside vegetation often increases streambank erosion, reduces the available streamside habitat, and increases water temperatures. Increased water temperature increases oxygen demand and fish disease (Lyon and others 1978). Increased nutrient loading often occurs after a fire and may be beneficial by increasing stream productivity (Lyon and others 1978). Adverse stream-related impacts can be lessened by leaving a buffer of vegetation around streams.

Competitive Interactions Between Wildlife Species

Fire may alter the competitive interactions between animals; with the result of one species increasing at the expense of another. An interesting study of how fire can alter the competitive relationships between ungulates was conducted in Banff and Jasper National Parks of Alberta, Canada (Flook 1964). Before the fire, mule deer, moose, and bighorn sheep were relatively common, and elk were relatively uncommon. Each of these species lived in separate habitats and interactions were relatively rare. Widespread fires encouraged grassland and shrubland that benefited the elk. The elk moved into many new areas and competed vigorously with mule deer for food and cover and with bighorn sheep and moose for food. As a consequence of habitat changes brought on by fire, and competition from elk, moose, bighorn sheep, and mule deer declined in numbers (Flook 1964).

Evaluating the effects of fire or any other management practice, on multiple wildlife species becomes quite complex. Thomas (1979) devised a matrix type approach to analyzing potential impacts of management practices on all forest species in the Blue Mountains of Oregon. This required an understanding of the habitat requirements of the wildlife species, the requirements filled by the present vegetative community, and the requirements filled by the post burn vegetation.

Manipulating Wildlife Habitat With Fire

The first step in planning a habitat manipulation program must be to clarify the objectives. Is management for species diversity the overriding consideration? If so, the habitat should be developed for maximum diversity of communities, successional stages, and ages of plants. If a single animal species is to be given priority, then habitat manipulation should be planned with that species in mind, with less concern for requirements of other species. Are recreational and aesthetic considerations of overriding importance in the area? If so, the vegetation manipulation plan will require a much different approach. Often multiple use objectives require consideration of all species and uses. However, certain smaller areas may be selected as having the greatest potential for a particular use and can be managed primarily for that use. These are some of the questions that must be addressed early in the planning stages.

Severson and Medina (1983) stated that wildlife habitat managers have four facets of vegetation manipulation to consider when designing habitat modifications: (1) the amount of hiding and thermal cover necessary to fulfill the animals’ needs, (2) the amount of area needed for food production, (3) the optimum arrangement (interspersion) of various cover and food producing areas to realize, and (4) the optimum amount of edge. When considering these four facets of vegetative manipulation the habitat manager must seek to find the limiting factor(s) of the population(s) in question. Adequate information is seldom available on all the possible limiting factors. As a result, the habitat manager should acquire more information, or proceed by improving the quality of the "probable limiting factors" in the habitat. General reviews and discussions of habitat improvement techniques can be found in Thomas (1979), Yoakum and others 1980, and Severson and Medina (1983).

Successful habitat management must be based on a thorough understanding of the fact that the vegetation on a given site does not remain the same from year to year if left alone (Leopold 1933). Each successional change is characterized by a certain assemblage of plant species that have different kinds and amounts of cover and food. Succession can be hastened by planting climax species, protection from grazing, and fire. Even with this help, accelerating the pace of succession may be very slow. Succession can be rapidly set back through the use of prescribed burning (fig. 13). The challenge to the habitat manager is to ensure that this change in plant succession is consistent with management objectives.

Several kinds of changes in the plant community are possible and should be considered in a habitat manipulation program. Fire can be used to change plant abundance, availability, dispersion, nutritive value, and species composition. Community dispersion, interspersion, and edge can also be altered with fire. Judicious use of fire can often produce the desired mix of these attributes in a plant community (fig. 14).

Figure 13—Selective spot burning in a mixed spruce and aspen community. Prescribed burning was used to set back succession on a prime elk summering area.

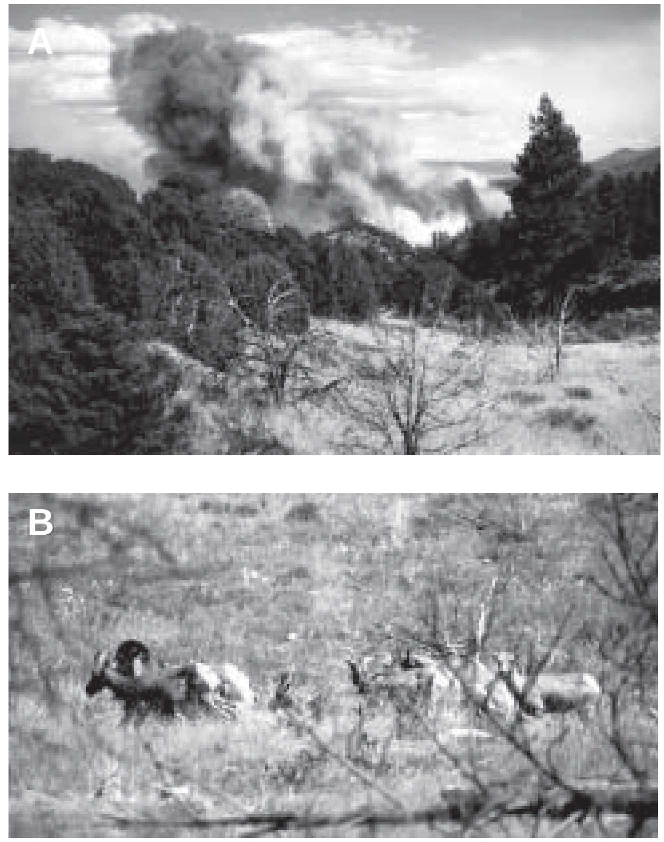

Figure 14—Juniper-pinyon being selectively burned for the benefit of Rocky Mountain bighorn sheep. (A) Area in foreground is a 3-year-old burn, and (B) Bighorn sheep on a 3-year-old juniper-pinyon burn.

Selectivity is required to produce the desired plant community with prescribed burning. Three types of selectivity can be used to effect the desired changes in plant communities: (1) selectivity of fire intensity, (2) species selectivity, and (3) area selectivity. Of these three types of selectivity, fire intensity is of overriding importance; understanding each is necessary to realize the potential of fire in habitat manipulation.

Fire intensity (described by fireline intensity) is the amount of heat released per unit of time per length of fire front. Fire severity incorporates both upward and downward heat fluxes and is an expression of the effect of fire on the ecosystem (Brown 1985a). It relates plant mortality to the extent of organic matter loss. Selectivity of fire intensity is obtained by selecting the proper mix of environmental conditions to achieve the fire intensity necessary to effect the desired change in the habitat. Burning under relatively cool, humid conditions results in fire with reduced severity that may not consume the ground litter. Conversely, burning under hot, dry, and windy conditions results in a more severe fire capable of removing vegetation and organic matter to the mineral soil. The differences between these two kinds of fires have profound influences on the resulting vegetation.

Postfire aspen sucker density is influenced by fire intensity and fire severity (Brown 1985a). Aspen sucker response to three levels of fire severity have been described by Brown (1985a) based on studies by Horton and Hopkins (1965) and Bartos and Mueggler (1981):

1. Low fire intensity and low ground char results in partial mortality of vegetation. Less than 50 to 60 percent of aspen trees are top-killed, and litter and upper part of soil duff is consumed. Suckering response is patchy and sparse.
2. Moderate to high fire intensity with moderate ground char top-kills nearly all of the aspen. Some patches of soil duff and charred material remain. Suckering is prolific.
3. Moderate to high fire intensity with high ground char top-kills nearly all of the aspen. Forest floor is reduced to ash and exposed mineral soil. Substantial suckering results.

Species selectivity is the ability to change the plant species composition of an area to meet the desired management objectives. Fire intensity, life form, and phenology all influence the differential mortality or stimulation of plants following fire. Plant species response to fire differs because of phenological variations at the time of burning, inherent susceptibilities to heat damage, regenerative abilities, and responses to the postfire environment. Individual plants may have different responses to fire because of local variations in fire temperature or microenvironment. The postfire assemblage of plants may have few species changes, as is often the case after grassland fires, or may be dramatically different in both species composition and structure, which occurs following some forest fires.

The precise path of plant succession, or the results of fire on a certain community depends on many interacting factors and may, therefore, be difficult to predict. It is the plant community, and the successional stages of it, that are of primary concern to the wildlife habitat manager and should be understood prior to any prescribed burning operation. Fortunately, there is sufficient information available on fire effects in many communities to allow several generalizations.

Each step in succession may last only a few months or as long as several centuries. Succession can be hastened by planting climax species, protection from abusive grazing, and from fire. The process of succession from one vegetation type to another can be very slow, even with helpful management. Succession can be set back by many kinds of disturbances; the most common of which are overgrazing by domestic livestock, cutting vegetation for hay or timber, plowing the soil, and burning.

Grasslands are usually well adapted to recurring fire regimes and are not drastically changed by fire. An increase in forbs is a common occurrence. Early successional animals such as bobwhite quail are often favored by these changes (Leopold 1933; Stoddard 1931). Woody plants vary considerably in their response to fire. Communities of woody plants without the ability to resprout following top removal, such as big sagebrush and Utah juniper, are often destroyed by fire. In contrast, communities with aggressive resprouters such as mesquite, willow, aspen, or Gambel oak retain similar species compositions but the aboveground portions of the communities may be drastically reduced in height while the stem density increases.

Area selectivity is the ability to burn certain areas, or a percentage of an area. This is a critical factor in determining the amount of dispersion, interspersion, and edge in the post-burn community. Area selectivity can be obtained by burning a series of small areas (fig. 14) or by burning at a time and place where the fire will not burn continuously.

Burning Techniques

Firebreak Considerations

Adequate firebreak construction is essential to the development of a successful prescribed burn. Firebreaks may consist of any area, whether natural or human-made, which successfully contains the fire under consideration. Natural firebreaks may be rivers, rock bluffs (fig. 15), or areas with insufficient vegetation to carry the fire. Human-made firebreaks may be roads (fig. 16), plowed fields, or areas constructed specifically to stop a prescribed fire.

Natural firebreaks provide a significant cost advantage when available, but specially developed firebreaks are routinely used in prescribed burning. These usually consist of a combination of mechanically removing vegetation down to the mineral soil for a width

Figure 15—Use of a river and rocky hillside as natural fire breaks in a prescribed burn.

Figure 16—Human-made firebreak in a juniper-pinyon prescribed burn.

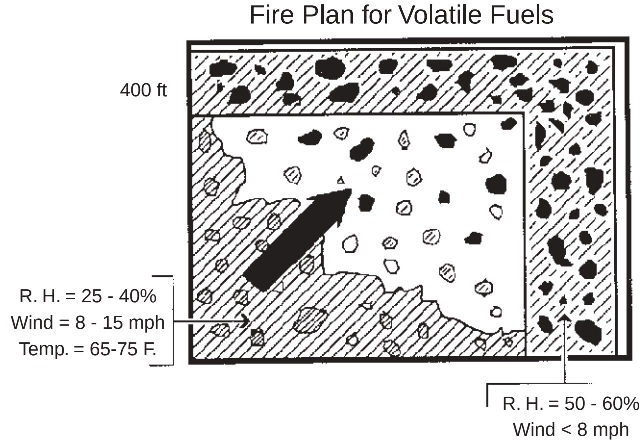

Figure 18—Fire plan for volatile fuels.

of 8 to 12 ft (2.4 to 3.7 m) and burning the vegetation in a strip around the area to be burned. Burning firebreaks usually occur under relatively mild conditions. Depending on the situation, this may mean burning the firebreak several months in advance or preparing the firebreak the morning of the main fire.

Burning in grassland fuels usually requires only a 100 ft (30.5 m) firebreak (fig. 17). However, burning in shrubby vegetation, particularly where the shrubs contain volatile oils, requires a much wider firebreak (fig. 18). The following burning prescriptions include suggested fireline widths, however, there is no substitute for experience and careful consideration of the unique features of each individual burning situation. For detailed information on fireline preparation, firing techniques, and the application of prescribed burning, refer to the excellent reviews on those subjects (Emrick and Adams 1977; Fischer 1978; Martin and Dell 1978; Mobley and others 1978; Schroeder and Buck 1970; Wright 1974; Wright and Bailey 1982).

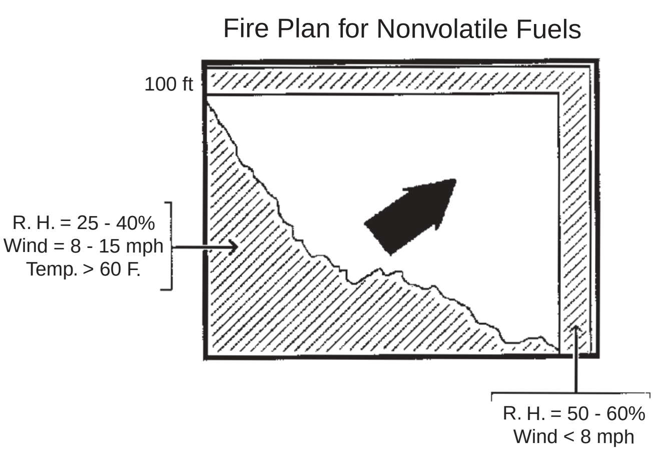

Figure 17—Fire plan for nonvolatile fuels.

Sagebrush Communities

Larger sagebrush types (fig. 12) often provide fuel sufficient to carry a fire. Sites dominated by dwarf species seldom support enough fuel to carry a fire.

Big Sagebrush-Grass

According to Beardall and Sylvester (1976), a minimum of 600 to 700 lb per acre (673 to 785 kg per ha) of herbaceous fuel is required to burn sagebrush grass communities. Where the fire is to be carried with herbaceous fuels, livestock grazing should be restricted during the growing season prior to the burn. This should help provide adequate fuel to carry the fire. Pechanec and Stewart (1944) determined that 20 percent cover should be the minimum amount of sagebrush to consider burning. Wright and others (1979) recommended early spring or late summer burning, when soil moisture is usually present down to 12 to 19 inches (30.5 to 48.3 cm). Soil moisture is less critical when burning in the fall.

The following instructions for burning sagebrush-grass range were suggested by Wright and others (1979) and Wright and Bailey (1982):

1. Prepare a fireline of 10 to 12 ft (3.0 to 3.7 m) width around the entire area to be burned. This fireline should expose the mineral soil.
2. Burn a 250 ft (76.2 m) blackline on the downwind side, when weather conditions are mild. Air temperature should be 60 to 70 °F (15.6 to 21.1 °C), relative humidity 25 to 40 percent, and windspeed 6 to 10 mi per h (9.7 to 16.0 km per h). These environmental conditions are most common in the early morning hours during the summer.
3. Burn the remaining area in the afternoon as air temperature reaches the maximum and relative humidity approaches its minimum. Recommended

environmental conditions are air temperature of 75 to 80 °F (23.9 to 26.7 °C), relative humidity 15 to 20 percent, and windspeed 8 to 15 mi per h (12.9 to 23.9 km per h).

Dense Stands of Big Sagebrush

Dense stands of big sagebrush surrounded by low sagebrush may be burned during hot, dry, windy days with no firelines (Beardall and Sylvester 1976). They suggested burning these areas in early spring when relative humidity is below 60 percent, windspeed is above 8 mi per h (12.9 km per h), and when there is more than 600 to 700 lb per acre (673 to 785 kg per ha) of fine fuel.

A technique for burning very dense stands of big sagebrush that does not require fireline preparation was developed by Neuenschwander (1980). This technique involves winter burning, with snow present, and is restricted to areas with greater than 50 percent sagebrush cover and a distance between plants of less than 50 percent of the average sagebrush height. With those restrictions, fire carried through sagebrush canopies when effective windspeed was above 5 mi per h (8.0 km per h) and the winter ignition index was greater than 29. The winter ignition index is determined using the following equation:

$$Y_1 = 96.64 - 91.20\,(X_1) - 1.1\,(X_2)$$
$$r^2 = 0.811$$

Where Y_1 = ignition index
X_1 = fine fuel moisture content of canopy (percent)
X_2 = relative humidity (percent)
and $Y_1 > 0+$

Under those conditions, only small areas burned. Winter sagebrush burning might be impractical in most areas because of stand limitations and the relatively few days with proper burning conditions (Neuenschwander 1980). However, where feasible, winter broadcast burning is inexpensive, and completely safe when snow is present. It requires no fireline construction or fire crews and can be used to create vegetation mosaics beneficial to both wildlife and livestock.

Cheatgrass Communities

Burning cheatgrass ranges is relatively easy if a continuous cover of dry cheatgrass is present. The critical aspect in burning this community is postfire management. Establishment of perennial grass species is very important. Fireline construction can easily be done with the wetline technique described by Martin and others (1977). Fires can be backed away from a single wetline or allowed to burn between two wetlines.

Martin and others (1982) suggested the following prescription for burning cheatgrass ranges: (1) burn after grasses have dried out and when soil surface litter is dry enough for the fire to consume cheatgrass seeds in the soil surface litter, (2) use backfires to create a blackline of 30 to 100 ft (9.1 to 30.5 m) on the downwind sides, and (3) burn with headfire when air temperature is 56 to 84 °F (13.3 to 28.9 °C), relative humidity is 20 to 45 percent, and windspeed is 0 to 10 mi per h (0 to 16.1 km per h).

Juniper-Pinyon

Prescribed burning in the juniper-pinyon zone (fig. 3, 11, and 14) is primarily used to reduce tree and shrub cover, allowing recovery of herbaceous species, or as a site preparation procedure for seeding efforts. The following guidelines are useful in planning and conducting prescribed fires in juniper-pinyon types.

Closed Stands of Juniper and Pinyon—Stands of juniper and pinyon with little or no herbaceous plants are difficult to burn. The areas become more difficult to burn as the percentage of juniper increases and pinyon decreases. With large fire lines, stands with over 300 trees per acre (741 or more per hectare) can be burned on hot, windy days (Blackburn and Bruner 1975; Truesdell 1969). These areas may require winds in excess of 35 mi per h (56.4 km per h) to carry a fire. The hazards of an escaped fire prevent most resource managers from burning under these conditions. However, in unusual situations where excellent natural fire breaks were present, prescribed fires have been successfully conducted under those conditions (Truesdell 1969). The following prescription is recommended (Wright and Bailey 1982) for burning closed stands of juniper-pinyon: (1) prepare a 10 ft (3.0 m) fire line around the area to be burned. On the downwind side, 500 ft (152.4 m) in from the outside boundary, construct a similar fireline parallel to the first. The downwind strips can be chained and windrowed; (2) windrows are to be burned in early spring or summer when vegetation of adjacent areas is still green. This burning should occur with an air temperature of 60 to 75 °F (15.6 to 23.9 °C), relative humidity of 20 to 35 percent, and windspeed of 0 to 10 mi per h (0 to 16.1 km per h); (3) the main burn area is prepared in the spring by dozing strips 20 to 50 ft (6.1 to 15.2 m) wide every 0.25 mi (0.4 km) and pushing the debris against the windward side of the standing trees. These fuels should be allowed to cure for 2 to 3 months; and (4) conduct the main burn in the summer with an air temperature of 80 to 95 °F (26.7 to 35.0 °C), relative humidity less than 10 percent, and windspeed greater than 8 mi per h (12.9 km per h). The fire intensity is built up in the windrows and carries through the adjacent standing trees.

Davis (1976) suggested chaining as an alternative method of preparing firelines in closed juniper-pinyon stands. The firelines would be chained in the winter, and in the spring when adjacent unchained areas had moderate conditions and green vegetation, the chained areas would be burned. Bryant and others (1983) stated that recently chained or dozed juniper (less than 100 days) can be safely burned if herbaceous fuel is less than 445 lb per acre (499 kg per ha), windspeed is less than 6 mi per h (9.7 km per h), relative humidity is above 45 percent, and air temperature is less than 86 °F (30.0 °C). The best fireline width is not known, but Wright and others (1979) suggested 300 ft (91.4 m) if little fine fuel is present in the surrounding area.

Pure stands of juniper are difficult to burn without a pretreatment that increases flammability or continuity. These areas require firelines and hot, dry, windy conditions. The distance between windrows may need to be reduced to only 250 ft (76.2 m). The difficulty in broadcast burning these areas may require large fire crews to ignite the scattered piles and windrows. Flammability may be increased by mechanical treatments or possibly with herbicide treatments on the area, or parts of the area, to be burned. The fuel continuity may be increased by one-way chaining the area with a relatively light chain. This treatment uproots very few trees but moves them to a fairly horizontal posture. This greatly reduces or eliminates the distance between trees and enables the fire to spread much easier.

More recent research into techniques of burning mature Ashe juniper in Texas with crown fires has added more information and suggestions (Bryant and others 1983). They studied the effect of dozed and windrowed juniper as an aid to igniting adjacent standing trees. Dozed trees left where they fell were ineffective in igniting a crown fire in the adjacent standing trees. Windrowed plots produced the best result for igniting the adjacent crowns when canopy cover exceeded 35 percent; windspeed exceeded 10 mi per h (16.1 km per h); air temperature was 73 to 91 °F (22.8 to 32.8 °C); relative humidity was 20 to 35 percent; and juniper leaf water content was 58 to 60 percent. Crown fires stopped when the distance between juniper trees exceeded 26 ft (7.9 m). Burning into less dense areas and using livestock to reduce fine fuel loads of fire lines was also effective (Bryant and others 1983). This method is limited to times and places with high winds, hot temperatures, and dense juniper stands, and has not been tested on juniper-pinyon communities of the Intermountain area. Nevertheless, it should be of considerable importance when it can be used.

Open Stands of Juniper-Pinyon With Grass Understory—In these communities, the fine fuel is used to carry fire from tree to tree (fig. 4). This requires 600 to 700 lb per acre (673 to 785 kg per ha) of fine fuel if it is uniformly distributed (Wright and others 1979). This method is restricted to areas with small trees (fig. 3). Trees larger than 4 ft (1.2 m) will rarely be killed unless the fine fuel load is sufficient to ignite the tree canopies.

Prescriptions for burning open juniper-pinyon stands containing a grass understory are similar to those for grasslands. However, additional precautions should be taken to reduce the potential for spotting. Information from Jameson (1962) and Dwyer and Peiper (1967) was used to prepare the following prescriptions: (1) prepare a 10 to 12 ft (3.0 to 3.7 m) wide fireline around the area to be burned. Use strip headfires to prepare a 100 ft (30.5 m) blackline on the downwind sides (Wright and others 1979). This is best done in the morning or early evening during spring and (2) ignite main fire with an air temperature of 70 to 74 °F (21.1 to 23.3 °C), relative humidity of 20 to 40 percent, and a windspeed of 10 to 20 mi per h (16.1 to 32.2 km per h) (Dwyer and Pieper 1967; Jameson 1962).

Martin (1978) studied western juniper mortality following fire under four sets of environmental conditions. All the sites studied had sufficient herbaceous fuel or sagebrush cover to carry the fire through the juniper stands. He subsequently suggested the following prescription for burning: (1) prepare a 200 ft (61.0 m) fireline on the downwind side of the area to be burned. Use backfires and short strip headfires to burn the fireline and (2) ignite the main headfire with an air temperature of 65 to 80 °F (18.3 to 27.8 °C), relative humidity of 17 to 23 percent, and a windspeed of 5 to 12 mi per h (8.0 to 19.3 km per h).

Mixed Juniper-Pinyon—Bruner and Klebenow (1979) reported a prescription for burning dense, mixed Utah juniper single leaf pinyon stands in Nevada without the use of firelines. They developed a simple index to aid in determining where and when these burns should be attempted. This index consists of total tree and shrub cover, air temperature, and maximum windspeed. The index is as follows:

$$\text{INDEX} = \text{tree and shrub cover (percent)} + \text{air temperature (°F)} + \text{maximum windspeed (mi per h)}$$

where, shrub and tree cover = 45 to 60 percent, air temperature = 60 to 75 °F (15.6 to 23.9 °C), windspeed = 5 to 25 mi per h (8.0 to 40.2 km per h), and relative humidity is less than 25 percent. The index must equal or exceed 110 for a fire to carry and kill large pinyon and juniper trees. At values less than 125, reignition may be necessary; above 130, conditions are too hazardous to burn.

This method is safe, economical, and useful for the areas in which it was designed. This prescription was developed on a series of fires that carried upslope into ravines. Ignition was aided by the upslope, thick stand of juniper-pinyon, and the high percentage of pinyon (greater than 90 percent) in the vegetation. Firelines were not required because of the sparse vegetation outside of the ravines. Most of the burns were small, ranging from 5 to 60 acres (2.0 to 24.3 ha).

Aspen

Aspen forests have generally been considered difficult to burn (fig. 1, 8, and 13). Fuel loads and flammabilities of these communities vary greatly. Careful selection of locations where fuels are sufficiently flammable to offer a high probability of success is critical in aspen communities. Fortunately, some quantitative guidelines have been developed for burning in aspen communities. Brown (1985a) states that at least 80 percent aspen top kill was necessary to achieve effective suckering following burning. He also stated that flame lengths averaging 1.3 ft (0.4 m) were a minimum flame size for sustained spread and for consistent aspen top kill.

Flammability of aspen and aspen-conifer communities varies with leaf litter abundance, downed woody material, herbaceous vegetation (table 3), shrubs, conifer reproduction, slope, grazing intensity, fuel water content, crown closure, and pocket gopher activity (Brown 1985a). Aspen communities can be separated into five fuel classes (table 4) with respect to potential for prescribed burning (Brown 1985a).

Table 3—Vegetation classification of aspen fuels and flammability[a].

	Vegetation and fuel characteristics			
Characteristics	**Aspen shrub**	**Aspen tall forb**	**Aspen low forb**	**Mixed shrub**
Overstory species occupying 50 percent or more of canopy	Aspen	Aspen	Aspen	Conifers
Shrub coverage (percent)	>30	<30	<30	>30
Indicator species for community type	*Prunus*	*Bromus*	*Ranunculus*	*Prunus*
	Amelanchier	*Heracleum*	*Mahonia*	*Shepherdia*
	Shepherdia	*Ligusticum*	*Arnica*	*Spiraea*
	Symphoricarpos	*Spiraea*	*Astragalus*	*Amelanchier*
	Artemisia	*Calamagrostis*	*Thalictrum*	*Symphoricarpos*
	Juniperus	*Rudbeckia*	*Geranium*	
	Pachistima	*Wyethia*	*Poa*	

[a]Adapted from Brown (1985a).

Table 4—Probabilities of successfully applying prescribed fire in aspen forests according to vegetation fuel classes and the influence of grazing and quantities of downed woody material[a].

	Vegetation, fuel class				
Condition	**Aspen shrub**	**Aspen tall forb**	**Aspen low forb**	**Mixed shrub**	**Mixed forb**
Ungrazed, light downed wood	Good	Fair	Poor	Good	Fair
Ungrazed, heavy downed wood	Good	Fair	Poor	Good	Good
Grazed, light downed wood	Fair	Poor	Poor	Fair	Fair
Grazed, heavy downed wood	Good	Poor	Poor	Good	Fair

[a]Adapted from Brown (1985a).

The probability of successful burning of the aspen and aspen-conifer communities can be better predicted when grazing and the amount of woody fuel are considered. Using the probability of successful burning information (table 4) developed by Brown (1985a) allows concentration on sites with the greatest likelihood of success. These probabilities can be greatly modified by factors such as aspect, slope, fuel continuity, and fuel water content.

Once a potential site is selected, fuel water content should be carefully considered. The best indirect indicator of live fuel water content is time of year (Brown 1985a). In most aspen communities, the snowpacks do not completely melt until the spring greenup. Summers are usually dry in the Rocky Mountain aspen region, and fuels dry through late summer and fall (DeByle 1985b). As fall approaches, the probability of a major precipitation event increases (DeByle 1985b). The most reliable time to burn aspen communities is often after live vegetation is cured, and prior to fall precipitation.

Live Aspen—Burning live aspen forests usually requires relative humidity below 35 percent. Wright and Bailey (1982) stated that acceptable burning conditions and a proven prescription for aspen parklands in Alberta are: (1) relative humidity of 15 to 30 percent; temperature 65 to 80 °F (18.3 to 26.7 °C); 4 to 15 mi per h (6.4 to 24.1 km per h) windspeed; at least 14 days since the snow melted in adjacent grassland or 3 drying days since the last rain; and a surface duff water content of less than 20 percent; (2) prepare a 500 ft (152.4 m) fireline on the leeside and a 100 ft (30.5 m) fireline on the remaining sides; and (3) strip headfires are the best ignition method. When burning in aspen parklands, where groves of trees are surrounded by grassland, the grassland can be burned to provide a fireline for the aspen fire.

Dead Aspen—Aspen forests can be killed with an herbicide and burned 2 years later under fairly moderate conditions (Wright and Bailey 1982). Under these conditions, burning should not occur when relative humidity is less than 35 percent because the dead aspen bark becomes a dangerous firebrand. Wright and Bailey (1982) recommended the following prescription for burning dead aspen forests: (1) relative humidity of 35 to 50 percent; temperature 40 to 75 °F (4.4 to 23.9 °C); 2 to 12 mi per h (3.2 to 19.3 km per h) windspeed; at least 10 days since the snow melted or three drying days since the last rain; and a surface duff water content of less than 20 percent; (2) prepare a 400 ft (121.9 m) fireline on the leeside and a 100 ft (30.5 m) fireline on the remaining sides; and (3) strip headfires are the best ignition method if a person can walk around the perimeter of aspen groves. In a continuous forest, perimeter firing is recommended because strip headfiring is too dangerous in a dead forest.

When a dead aspen forest is totally surrounded by live aspen forest, a 1 m (3.3 m) fireline can be constructed around the perimeter of the dead forest. Relative humidity should be 40 to 50 percent (Wright and Bailey 1982). More detailed information on prescribed burning of aspen communities can be found in Brown (1985a).

Management After Burning

The success of any wildland rehabilitation project is largely determined by postfire management (Young and others 1985). Judicious application of management practices based on the unique attributes of the resource with consideration for additional concerns created by burning are the key to successful wildland rehabilitation. The recommendations made by Pechanec and Stewart in 1944 are still appropriate for managing western rangeland after burning. They stated: (1) protection of burned areas from trailing by livestock during the first fall at least; (2) protection of burned areas from grazing for one full year; (3) light grazing for the second year, and thereafter no heavier than the range can support permanently; (4) the same grazing management for burned and reseeded areas as for areas not in need of reseeding; (5) for areas with more than half the understory in cheatgrass, special protection against recurrent accidental fires; and (6) for accidentally burned areas, at least as good management after burning as that demanded for the best results from planned burning.