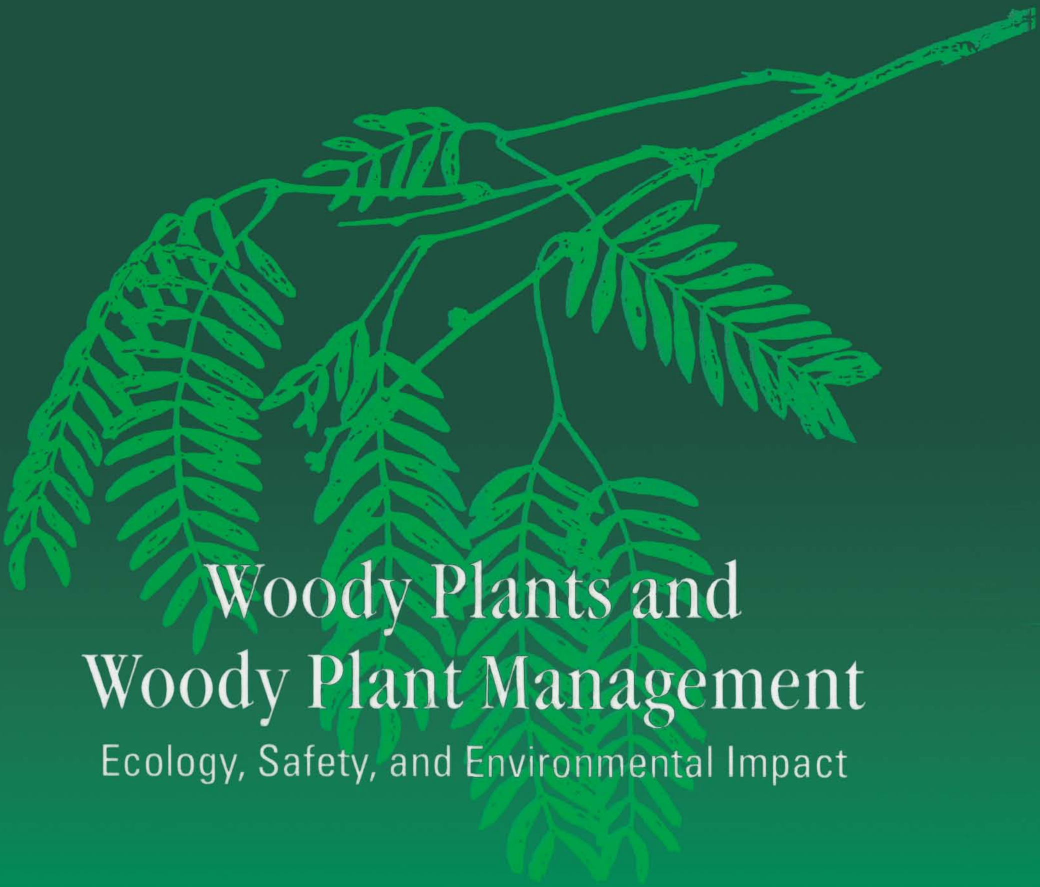

Woody Plants and Woody Plant Management

Ecology, Safety, and Environmental Impact

Rodney W. Bovey

Woody Plants and Woody Plant Management

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To my four sons, Seth Ivan, Todd Evin, Shawn Erin, and Cary Lane, who, along with their families, are all talented professionals in widely divergent careers. They have greatly enhanced my life and career. It's been a fun journey and I am most grateful for their love and support.

Preface

The book is about managing woody plants that may be undesirable for wildlife, livestock, or wood production. Managing woody plants is sometimes very challenging and requires judicious use of the best management practices in balancing recreation, wildlife needs, watershed yield, livestock use, economics, conservation of resources, and human needs and goals.

Some woody plants that have no apparent redeeming value are difficult to manage because they resist all forms of suppression and dominate the landscape. They may also be costly to treat. Many, however, are desirable for food and shelter for wildlife, human recreation, aesthetics, and soil and water conservation. But when a woody plant species becomes so dominant that it markedly reduces animal and plant diversity, interferes with recreation, livestock, and wildlife production, or becomes a fire hazard, some control method may be needed. On forested land, undesirable brush may interfere with wood production, wildlife habitat, and herbaceous plant and animal diversity. On many noncrop areas, such as utility rights-of-way, roadways, industrial sites, airports, and areas around buildings and structures, woody plant control may be necessary to improve visibility, safety, and aesthetics and to protect expensive facilities.

Although the literature on woody plant management is extensive, it is scattered throughout many diverse sources that span more than 50 years. The purpose of this book is to bring together the most significant literature and data into one reference.

The book covers the significance and botanical nature of woody plants, the history and use of fire, biological, mechanical, and chemical control methods, and combinations of these methods where appropriate. Also examined are herbicide chemistry and properties, toxicology and safety, residues and environmental impact, and how herbicides are applied. The fate and activity of herbicides in plants and their effects on plants and animals are described. The response of over 370 woody plants in North America to commercially available herbicides is presented in Chapter 12. Finally, Chapter 8 provides an update on the phenoxy herbicide controversy (Agent Orange).

To complete the book, the economics of woody plant control and growing woody plants for experimental purposes is discussed, as well as future research needs and recommendations.

Special thanks are extended to Mary Alice Peel and Julie Preiss for typing and correcting the manuscript and to Beth Ellison for her encouragement and administrative assistance.

Rodney W. Bovey

Contents

Woody Plants and Woody Plant Management

1

Significance and Botanical Nature of Woody Plants

I. INTRODUCTION

Williams et al. (1968) indicated that about one-third of the Earth is land area, or 14 billion hectares (ha). Approximately 10% is farmed, 28% is in forest (which is grazed at least part-time), and 15% is covered with icecaps or fresh water, leaving 47% or nearly half of the globe for grazing by livestock or game animals. Such land is usually only suitable for grazing because it is too steep, shallow, sandy, and wet, cold, or saline for crops. Williams et al. (1968) indicated that 75% of the domestic animals and most wildlife depend upon grazing lands for survival. Such land is also extremely important as watersheds, for conservation, for wood, medicinal, and industrial compounds, for mining resources, and for recreational purposes. Forests and grasslands are also apparently more efficient in carbon dioxide removal from the atmosphere than cropland, which according to some investigators may be increasing to the point of causing unacceptable climatic change unless reversed (Woodwell, 1978; Mayeux et al., 1991).

Of the 0.4 billion ha of range and pastureland in the United States (Thomas and Ronningen, 1965), about one-third is estimated to be infested with undesirable woody plants (Allred and Mitchell, 1955; Williams et al., 1968). Klingman (1962) indicated that woody plant infestations of rangeland included 30 million ha of juniper (*Juniperus* spp.), 28 million ha of mesquite (*Prosopis* spp.), and 38 million ha of sagebrush (*Artemisia* spp.). The ha infested with junipers, sagebrush, and mesquite have probably changed little or have increased in the last

35 years, since during this time little change occurred in the 23 million ha of honey mesquite growing on Texas rangelands in spite of control efforts (Bovey, 1998). Platt (1959) reported ha infested from a survey of 36 range authorities in the western United States and Canada. A total of nearly 240 million ha of land covered with problem woody plants were reported, with an additional 105 million ha of herbaceous weeds (many poisonous to livestock) indicated, for a grand total of over 345 million ha infested. Platt (1959) indicated some acreage was counted more than once because of interspersed stands of two or more undesirable species. Platt (1959) further stated, however, that it was not total number of ha that were important, but the ha requiring treatment for undesirable plants. Platt (1959) reported that sagebrush (*Artemisia* spp.), snakeweed (*Gutierrizia* spp.), juniper (*Juniperus* spp.), creosote brush (*Larrea* spp.), cactus (*Opuntia* spp.), mesquite (*Prosopis* spp.), and scrub oak (*Quercus* spp.) occurred on 16 million ha or more each of U.S. western rangelands, with about 13 major herbaceous weeds included.

Le Clerg et al. (1962) estimated that annual losses in forage production due to weeds on pastureland and rangeland in the 31 eastern states was 20% and 13% for rangeland in the 17 western states. When the cost of control measures was included with forage loss, the total loss for the United States was $1 billion. The loss did not include weed problems in establishing forage plants or losses due to poisonous plants or plants that cause mechanical injury to animals from needles, thorns, or other means.

Additional benefits of woody plant control in fostering sound range and pasture management and improved forage production include herbaceous weed control, increased quality and quantity of animal products, increased ranch and domestic water, better recreational opportunities, such as hunting, fishing, hiking, and picnicking, decreased number of pests, and decreased pollution (poisonous plants), resulting in both a better dollar return to the rancher and consumer and improved conservation practices.

Walker (1973) indicated timberlands supporting important amounts of undesirable vegetation in the United States total 120 million ha, or a conservative estimated annual loss of 0.4 billion cubic meters of lumber due to weeds alone. Walstad (1973) stated that about 36 million ha of forestland in the South needs timber stand improvement, including suppression of low-quality hardwood species. On an operational level foresters indicate that weed control can increase timber volume production in southern pine plantations by 14% and by 25% in natural stands.

Brush or undesirable woody plants are not confined to forest and rangeland but may become majors problems around industrial buildings and structures, railroads, roadways, overhead power lines, fences, vacant lots, airports, military installations, canals, ditch banks, cropland, and similar locations where they may interfere with safety, visibility, transportation, irrigation, recreation, or other activities of animals and man.

Woody plant problems are not confined to the United States; they are a worldwide problem. Little and Ivens (1965) cited the work of the IBEC Research Institute in New York, indicating that leiteiro (*Tabernae/montana fuchsiifolia*), amendoim de campo (*Pterogyne nitens*), a cyperaceae, and two shrubs (*Acacia polyphylla* and *A. paniculata*) are serious pasture weeds in Brazil. In Cuba, marabu (*Dichrostachys nutans*) is an important brush weed with growth characteristics reported similar to leiteiro. Herbicide 2,4,5-T or the substituted ureas were effective as basal sprays and soil treatments, respectively. Tschirley (1968) reported on herbicides to control a number of woody plants growing in Texas and Puerto Rico. The Puerto Rican treatments included guara (*Cupania americana*), mango (*Mangifera indica*), pomarrorsa (*Eugenia jambos*), camasey (*Miconia prasina*), common bamboo (*Bambusa vulgaris*), palma de sierra (*Prestoea montana*), and mixed semievergreen forest and evergreen rain forest. Although some of the species may not be considered brush problems the research program greatly expanded our knowledge of the response of tropical and subtropical woody plants to herbicides. Picloram was one of the more effective herbicides of the many investigated.

Willard (1973) studied the effectiveness of a backfire and rapidly moving headfire on dense shrubland in Argentina. Main woody trees included calden (*Prosopis caldenio*), algarobo (*P. flexuosa*), and sombra de toro (*Jodinia rhombifolia*). Shrubs included piquillin (*Condalia microphylla*), molle (*Schinus fasaicu-latus*), chanar (*Geoffroea decorticans*), jarilla (*Larrea divaricata*), and alpataco (*Prosopis alpataco*). The Monte region of central and western Argentina contains nearly 6.0 million ha of thorny shrubland. Wildfires are common in the region during the dry summers and are a hazard to livestock, wildlife, and man. Willard (1973) suggests prescribed burning for brush control in the Monte region of Argentina.

While land managers and scientists were optimistic about herbaceous and woody plant control in the 1950s to the 1980s when costs were reasonable and new herbicides and nonchemical methods were coming on stream, time has proven that wholesale eradication of weeds and brush was not possible or desirable.

Today land managers can use brush management to attain multiple benefits for society, including wildlife habitat management, watershed enhancement, aesthetics, and improved livestock-carrying capacity (Hanselka, 1997). The brush sculptor concept is the need to assess an integrated pest management (IPM) approach then integrate various brush management technologies (mechanical, herbicide, fire, and biological), monitor results, and adjust management strategies as needed. Sculpting brush allows the landowner or manager to optimize the value of his resource for livestock, wildlife, aesthetics, recreation, water, and real estate, while providing the desired products and services.

II. WHAT IS A WOODY PLANT?

Woody plants are plants that produce secondary growth in the form of wood. The mechanical support provided by the wood allows them to grow taller and effectively compete for available sunlight. They are always perennial, and the wood is produced over the lifetime of the plant (Rubin, 1997).

Because of the perennial and vigorous nature of woody plants they are sometimes difficult to manage when they become overabundant and dominate landscapes with purposes counter to land management.

Woody plants provide valuable wood products, browse for wildlife and livestock, cover and shade for wildlife, livestock, and man, water and soil conservation, medicinal extracts, hunting, recreation, human food, beauty, and many other benefits. When some woody plants become overly aggressive and dominant, possess no apparent redeeming value, and cause economic loss and management problems some control practice may be desired, however.

III. CHARACTERISTICS OF WOODY PLANTS

A. Perennial Nature

Control of undesirable woody plants is sometimes difficult because they may be vigorous perennials that live many years. They may reproduce by seed and vegetatively by basal stem buds, root sprouts, or rhizomes such as mesquite (*Prosopis glanlulosa* Torr.), huisache [*Acacia faresiana* (L) Wild.], and Macartney rose (*Rose bracteata*) Wendle.) Once these plants are injured by cutting, fire, animals, or chemicals they have the ability to regenerate from buds, root sprouts, or rhizomes. By removing top growth, apical dominance may be removed and dormant buds may be activated and produce new shoots. The new shoots grow uninhibited to produce mature plants unless they are further disturbed by top removal. Woody plants are adapted to survive injury from frost, fire, cutting, and other disturbances.

B. Competition

Woody plants may be strong competitors with other woody plants and herbaceous vegetation. They may grow tall and shade and deprive lower-stature plants of light. Some have deep and extensive root systems that allow them to grow in hostile environments to extract soil water and nutrients more efficiently than other plants. Some have the ability to shed leaves, produce smaller, thicker, cutinized leaves that resist heat, harvest light more efficiently, and resist desiccation in times of drought. By shedding excess leaves or slowing down metabolically, the plant may become dormant until a more favorable environment exists, while neighboring plants may suffer or die of desiccation. In areas devoid of vegetation from drought or other reasons the seeds of woody plants may establish seedlings during periods of ample rainfall and further infest the area.

C. Unpalatable

Many woody plants on rangeland have thorns and appendages or chemical composition unattractive to grazing animals. Because of causing possible injury, dense impenetrable stands, or offensive taste, these plants are essentially unmolested and grow and reproduce without interference. If grazing animals selectively utilize other woody plants and herbaceous vegetation near them, they are allowed to grow inhibited and spread, and may become serious weeds.

IV. CAUSES FOR ENCROACHMENT

Vallentine (1989) lists eight primary factors causing or contributing to the increase, spread, and invasions of noxious plants on grazing lands in the western United States, including: 1) grazing of domestic livestock (where the more desirable forage is reduced because of selective grazing, overgrazing, improper grazing season, or rigid livestock members), 2) reduction of fire, 3) seed transport by grazing animals, 4) weed seed dissemination by small animals, 5) climate fluctuations, 6) cultivation and subsequent abandonment, 7) local denudation (includes roads, railroads, stock trails, industrial areas, mining, farmsteads, and other locally denuded areas), and 8) increase in commerce (transport of weed seed into new areas).

Archer (1994) argues that selective grazing by large numbers and high concentrations of livestock has been the primary force in altering plant life-form interactions to favor unpalatable woody species over graminoids. Mayeux et al. (1991), however, indicated that increasing atomospheric CO_2 levels favor the C3 broadleaf herbaceous and woody species over warm-season perennial grasses (C4 plants) on rangelands. They hypothesize that increased atmospheric CO_2 causes vegetation change on rangelands rather than overgrazing, suppression of fire, and climate changes.

Archer (1994), however, cites many exceptions that limit the utility of the atmospheric CO_2 enrichment hypothesis as a robust explanation of the cause of woody plant encroachment into grasslands.

Archer (1994) cites numerous historical accounts and photographic records indicating that in the last 50 to 100 years shrublands, woodlands, and forests of North America have expanded and replaced what were grasslands and savannas at the time of European settlement. Early settlers in north-central and southern

Texas indicated little woody vegetation in the mid-1800s, with only a few scattered honey mesquite trees. Today honey mesquite occurs on at least half of Texas rangeland along with many other species of woody plants, despite some control practices (Bovey, 1998). Archer (1994) suggests that replacement of grasslands and savannas with shrub and woodlands dominated by unpalatable species appears to have been rapid (50 to 100 years), nonlinear, accentuated by climatic fluctuation, locally influenced by topoedaphic factors, and irreversible. Archer (1994) states that past industrial atomospheric CO_2 enrichment and climate change may have facilitated shifts from grass to woody plants but that there is a strong link between livestock grazing and woody plant encroachment. This has occurred because of livestock preference for grasses versus woody plants, alteration of soil structure and chemistry, seed dispersal, and fire reduction.

V. LONG-TERM WOODY PLANT ENCROACHMENT

A. Mesquite and Associated Plants

Brown (1950) studied woody plant encroachment for an 18-year period (from 1931 to 1949) on a desert-grassland in the Santa Rita Experimental Range in southern Arizona. Changes in velvet mesquite and burroweed (*Haplopappus tenuisectus*) were directly correlated with grazing pressure. Total protection from grazing did not retard mesquite encroachment or decrease burroweed. Velvet-pod mimosa (*Mimosa dysocarpa*) and fern acacia (*Acacia angustissima*) were reduced by drought-aggravated grazing injury. The desert grassland is indicated by this study to be subclimax to a desert shrub climax in southern Arizona.

Branscomb (1958) studied shrub invasion over a 30-year period in southern New Mexico semidesert grassland on the Jornada Experimental Range. Twelve percent of the total area formerly classed as grassland was dominated by shrubs. Honey mesquite was the principal invader, having increased its original acreage by 107%. Tarbush-creosote-type vegetation occupies 8% less area than before; snakeweed (*Gutierrezia sarothrae*)-dominated acreage was reduced by one-half. Grazing pressure has disseminated noxious plant seed and weakened the grass plants and removed fuel for fire. Wildfires prior to white settlement was indicated as the factor keeping grasslands free of shrubby invaders.

From 1935 to 1980 honey mesquite attained complete dominance, and many new mesquite dunes formed on the study area on the Jornada Experimental Range (Hennessy et al., 1983). Black grama (*Bouteloua eriopoda*) had relatively high frequency in 1935 but completely disappeared by 1980 on both grazed and nongrazed areas. Mesa dropseed (*Sporobolus flexuosus*), fluffgrass (*Erioneuron pulchellum*), and broom snakeweed increased in abundance, even during the drought period between 1950 and 1955. Only 25% of the perennial forbs present in the period from 1935 to 1955 were found in 1980.

Bogusch (1952) indicated that much of the region lying between the Nueces River and the Rio Grande was originally grassland. Bogusch (1952) indicated that honey mesquite was the primary invader, and wild game and buffalo had no importance in the spread of mesquite. He further stated fencing restricted cattle movement and increased grass damage, providing opportunity for shrub invasion.

B. Sagebrush Domination

Lommasson (1948) indicated that the big sagebrush of the high grasslands of the Gravelly Range of the Beaverhead National Forest in southwestern Montana will maintain itself indefinitely under natural conditions. This conclusion was the result of a 31-year-old study by the U.S. Forest Service. From 1882 until about 1914 little grazing use (buffalos killed off) was made of the range, and sagebrush became dominant. Since 1914 the area has been grazed by sheep. By 1945 sagebrush plants averaged 61 years in age by growth ring count. They became established in 1885, and in 1915 when the study began they were 31 years old.

In contrast, Robertson (1971) stated that a 30-year rest enabled a 20-acre tract of eroded sagebrush-grass range in northern Nevada to increase its vegetal cover in all life forms. The cover of perennial forbs increased the most, 85%. Thurber needle grass increased 7-fold. Only annual forbs and locoweed declined. Bluebunch wheatgrass reestablished naturally in favored spots. Newly cleared and seeded range outside the exclosure produced three times as much grass forage as was produced after long rest without clearing. Robertson (1971) further indicated that while the plot data showed improved forage cover by long rest, restoration would be quicker by brush control and seeding.

Data from permanent vegetation transects, established on the Idaho National Engineering Laboratory Site in 1950, were analyzed to determine what changes had taken place in the vegetation complex over the past 25 years in the absence of grazing by domestic livestock (Anderson and Holte, 1981). Cover of shrubs and perennial grasses nearly doubled. Shrub cover in 1975 was 154% greater than in 1950; this change was almost entirely due to increases in cover of big sagebrush between 1957 and 1965. Cover of perennial grasses increased exponentially over the 25-year period, from 0.28% in 1950 to 5.8% in 1975. This was paralleled by significant increases in density and distribution of the four most important grasses on the study area. The 20-fold increase in perennial grass cover has not been at the expense of the shrub overstory.

Hull and Hull (1974) indicated that explorers and early settlers found abundant grass and little sagebrush in Cache Valley in northeastern Utah and southeastern Idaho. Excessive grazing by livestock after settlement caused the grass to decrease and the sagebrush to increase. Most grassland areas were eventually plowed for dry-land or irrigated farming. In the dry-farm belt, however, there are many steep or rocky slopes, inaccessible corners, and similar areas that have not been plowed, irrigated, heavily grazed, or burned in recent years. Many of these areas support vegetation that, except for increased sagebrush, is undoubtedly similar to that described by explorers, early settlers, and historians.

In contrast, Vale (1975) reviewed 29 journals and diaries for their vegetation descriptions of the sagebrush-grass area in an attempt to assess the relative importance of herbaceous plants and woody brush in the northern intermountain west. The early writings suggest a pristine vegetation visually dominated by shrubs. Stands of grass apparently were largely confined to wet valley bottoms, moist canyons, and mountain slopes, with more extensive areas in eastern Oregon near the Cascade range. The major area was apparently covered by thick stands of brush.

C. Juniper Invasion

As a means of studying inter- and intrazonal invasion in black sagebrush (*Artemisia nova*) communities, six maturity classes were established for pinyon (*Pinus monophylla*) and juniper (*Juniperus osteosperma*) in east-central Nevada (Blackburn and Tueller, 1970). Pinyon and juniper invade and increase in black sagebrush communities until the understory is eliminated. Juniper invades first and tends to be replaced by pinyon. Accelerated invasion by both species started in about 1921 and is closely related to overgrazing, fire suppression, and climatic change.

Johnsen and Elson (1979) studied vegetation changes over 60 years in central Arizona grassland-juniper woodland ecotone sites by matched photograph pairs. Grazing use markedly affected understory species. Juniper numbers and sizes increased markedly on hillside and rocky ridges, but did poorly on bottom land sites. Utah juniper rapidly reestablished on areas cleared in the 1950s and 1960s. Stands of shrub live oak, cliforse, mountain mahogany, and Apache-plume did not spread, but shrub crown cover increased greatly.

D. Kansas Bluestem Prairie

Postsettlement invasion of trees and shrubs in Geary County, Kansas Flint Hills, was assessed by aerial photos (Bragg and Hulbert, 1970). Tree cover increased 8% from 1856 to 1969 throughout the county except on regularly burned sites, where trees and shrubs were maintained at presettlement amounts. On unburned sites, woody plants cover increased 34% from 1937 to 1969. Herbicide spraying only slowed the invasion rate. Lowland soils rapidly increased in brush from 1856 to 1937. The authors concluded that on the Flint Hills, bluestem prairie rangeland burning was effective in restricting woody plants to presettlement amounts and soil type, and topography affected woody plant invasion.

VI. INDIVIDUAL WOODY PLANT PROBLEMS

There are many references to identify woody plant species, therefore taxonomic descriptions will be very brief and are provided only as an aid to diagnosing a brush problem. Woody plant problems of great importance will be given first, followed by other important brush species. (See Chap. 12 for more information on woody plants and their control.)

For positive identification (if needed) of the brush and proper management of the brush problem one can consult the local county agricultural extension agent or extension weed specialists or a private consultant, chemical company representatives, federal or state university weed scientists, or personnel of the Natural Resources Conservation Service of the USDA. Species given in this text will be numbered for reference.

1. Honey mesquite (*Prosopis glaudulosa* Torr.).
   Description: a woody, thorny, legume shrub or tree of varying height and longevity; has natural resistance to fire, drought, and livestock grazing; competes aggressively with other woody and herbaceous plants for water and plant nutrients because it is a deep-rooted phreatophyte. Leaves on honey mesquite are an alternate, deciduous, long-petioled, bipennately compound of two (occasionally three or four) pairs of pinnae; with 12 to 20 leaflets. Leaflets are glabrous, linear, acute, or obtuse at the apex, 3 to 4 cm long, and 0.5 to 1 cm wide. Legumes (pods) with seed are 10 to 22 cm long. Foliage is low in palatability, and excessive consumption of beans can cause livestock health problems (Jacoby and Ansley, 1991; Meyer et al., 1971; Vallentine, 1989; Vines, 1960; Welch and Hyden, 1996).
   Distribution: Honey mesquite is distributed from Kansas and New Mexico east into Oklahoma and Arkansas and across Texas (except for Piney Woods) into Louisiana (Vines, 1960).
   Reproduction: Produces seed pods abundantly; seed are brown oval 5 mm wide, 7 mm long, and 2 mm thick in the center (Meyer et al., 1971). Seed can readily germinate under favorable environment especially if they have passed through the digestive tracts of foraging animals (cattle), and will sometimes germinate and become established in dung (Jacoby and Ansley, 1991; Meyer et al., 1971). Seed is usually destroyed by insects, fungi, or rodents, but experiments have shown small numbers of seeds many lie dormant in the soil for several years. Established plants will usually sprout and regrow from the extensive basal buds and buds along the stem if injured. Cutoff plants may resprout at one to several places just below the point severed (Meyer et al., 1971).

Control: Destroy underground buds by mechanically uprooting, killing with diesel fuel oil, or using translocating herbicides such as triclopyr in diesel fuel as basal sprays or foliar sprays of triclopyr, clopyralid, or a 1:1 mixture of triclopyr and clopyralid. Successful control depends upon follow-up treatments to control new and missed plants from previous treatments (Welch and Hyden, 1996; Bovey, 1991).

2. Velvet mesquite (*Prosopis velutina* Woot.).
   Description: Velvet mesquite leaves are bipinnately compound with mostly four pairs of pinnae. Leaflets are pubescent and smaller than those of honey mesquite. Velvet mesquite is very deeprooted, sprouts from the stump, and is not easily damaged by disease or insects. Velvet mesquite foliage and pods are eaten by livestock and the seeds are an important wildlife food. Mesquite beans were important in the diet of the southwestern Indian (Vines 1960; Jacoby and Ansley, 1991).
   Distribution: Velvet mesquite occurs in mainly in southern Arizona, but is found in California and northern Mexico.
   Reproduction: Seeds readily pass through the digestive tracts of grazing animals and may germinate and grow where they fall. Established plants readily sprout from the underground basal bud and stem bud system when the top is injured.
   Control: Similar to honey mesquite.
3. Creosotebush [*Larrea tridentata* (Sesse & Moc. ex DC.) Coville].
   Description: Creosotebush is an evergreen shrub with an extensive lateral root system that dominates the landscape. It can attain a height of 3.3 m. The leaves are bifoliate; leaflets, small, opposite, divaricate, strongly falcate, united at the base, and pointed at the apex. They are oblong to obovate and 0.5 to 1 cm long, thick, dark green to yellowish green. They have a sticky resin that is strong scented. The flowers are also small, 0.8 to 1 cm long, the resulting carpels are one-seeded, indehiscent. The twigs are brown and the bark is dark gray to black. It has medicinal uses as an antiseptic and is employed as a treatment for rheumatism, venereal disease, tuberculosis, intestinal disorders, and emetic (Vines, 1960).
   Distribution: Crosotebush is a widespread desert shrub in most arid regions of the southwest, ranging from West Texas to California and south to Mexico and north to Nevada and Utah. It is poisonous to sheep but is not consumed by cattle. It is consumed by small mammals and antelope. It is often found with tarbush. Creosotebush produces germination and growth inhibitors that inhibit associated desert grasses (Vallentine, 1989).

Reproduction: Reproduction is by seed.
Control: Root plowing or soil-applied herbicides such as tebuthiuron.

4. Cholla [*Opuntia imbricata* (Haw.) DC.].
Description: Also referred to as walking stick cholla, it is an arborescent cactus with a short woody trunk and many erect candelabrumlike branches. It can attain a height of 2.7 meters and has a 25-cm-diameter trunk. It sometimes forms dense thickets. It has terminal purple flowers 4 to 6 cm long and 5 to 8 cm broad. The fruit is yellow, 2.5 to 4 cm long, and near hemispheric, and sometime falls from the plant. The seeds are small, 0.2 to 0.4 cm in diameter. It has spines 2 to 3 cm in length that are barbed (Vines, 1960).
Distribution: Texas north to Oklahoma and Kansas, south and west through New Mexico (Vines, 1960).
Reproduction: Spread by seed and vegetatively by the cylindric joints removed from the parent plant (Welch and Hyden, 1996).
Control: Individual plant treatment with foliar-applied herbicides such as picloram (Welch and Hyden, 1996).
5. Tasajillo (*Opuntia leptocaulis* DC.).
Description: Tasajillo cactus, also known as tesajo or pencil cactus, has a bushy appearance and is usually less than 1.5 meters tall. The stems are cylindric, with small, inconspicuous greenish flowers. The fruit is globular, small (less than 2.5 cm), red, and fleshy. The leaves (pads) are 1.3 cm or less, acute, early deciduous. The stems are various shades of green, branches slender, ascending, cylindric 0.6 to 1.2 cm in diameter or larger with joints varying in length from 2.5 to 25 cm. Red fruit is attractive to wildlife (game birds) (Vines, 1960).
Distribution: Grows at elevations to 915 meters in Texas, usually west of the Brazos river, west through New Mexico to California; south in Mexico to Puebla.
Reproduction: Spreads by seed and vegetatively by joints removed from the parent plant (Welch and Hyden, 1996).
Control: Foliar-applied herbicide, such as picloram.
6. Prickly pear cactus (*Opuntia* spp.) There are many species of prickly pear in the United States, and they respond in a similar manner to herbicides.
Lindheimer pricklypear (*Opuntia lindheimeri* Engelm.).
Description: A thicket-forming cactus with heavy thick large pads growing in clumps 1.5 to 3 meters tall. It has a definite trunk, often prostrate; flowers bright and showy, yellow to orange to red; fruit large (to 8 cm long), red to purple; joints green to bluish green, obovate; spines variable and absent on some joints (Vines, 1960).

Ranchers may burn off spines and use as supplemental cattle feed. It provides protection and some feed for wildlife from fruit and from the cladophylles. It is also troublesome to ranchers as a weed (Scifres, 1980).
Distribution: Southern and western Texas.
Reproduction: Spread by seed and vegetatively by pads (cladophylles).
Control: Foliar-applied picloram sprays. Prescribed burning used in combination with low rates of foliar-applied picloram is very effective (Welch and Hyden, 1996).
Engelman pricklypear (*Optunia engelmannii* Salm-Dyck) is a common pricklypear of the Southwest (Vines, 1960). It is a bushy cactus and grows to nearly 2 meters tall without a definite trunk. It is found in Trans-Pecos Texas, west through New Mexico and Arizona, north to Nevada and Utah, and south to Mexico. Control is similar to Lendheimer pricklypear cactus.

7. Broom snakeweed (*Gutierrezia sarothroe* Britt. & Rusby).
   Description: Plant bushy, herbaceous above and woody toward the base, attaining a height of 10 to 40 cm. The branches are numerous, erect, and redivided into slender branchlets. It has numerous small yellow flowers. Fruit are oblong achenes.
   Distribution: West Texas, New Mexico, Arizona, California, Utah, Montana, Idaho, Nevada, Kansas, and Saskatchewan (Vines, 1960).
   Reproduction: By seed.
   Control: Soil-applied herbicides such as tebuthiuron (Welch, 1997) or foliar-applied herbicides such as picloram, picloram plus 2, 4-D, picloram plus dicamba or metsulfuron.
8. Sand sagebrush (*Artemisia filifolia* Torr.).
   Description: Rounded aromatic shrub, freely branched, usually less than 1 meter tall: flowers in dense, leafy panicles; fruit an achene, glabrous, without pappus; alternate leaves sessile, often fascicled, usually entire; lower leaves often divided into threadlike divisions; twigs slender, pubescent dark gray to black (Vines, 1960).
   Distribution: An indicator of sandy soils to an altitude of 1800 meters in the panhandle of Texas, New Mexico, Arizona, Nevada, Colorado, Utah, and Chihuahua, Mexico (Vines, 1960).
   Reproduction: Spreads by seed, persists by sprouts from a shallow basal bud zone (Welch and Hyden, 1996).
   Control: Deep plow with a disk plow or apply foliar herbicides, such as the low volatile ester of 2, 4-D. (Welch, 1997).
9. Big sagebrush (*Artemisia tridentata* Nutt.).

Description: Big sagebrush is the most widely distributed shrub of the western United States. It varies in height from 0.5 to 3 meters. It is often dwarfed or prostrate from cattle grazing. Stems are mostly erect with ascending branches. Young parts are silvery, canescent, aromatic, and bitter to the taste. Flowers are borne in panicles 10 to 25 cm long or 2 to 10 cm wide, sometimes spikelike, often leafy-bracted; heads numerous, bracts 8 to 18. Fruit are cylindric, turbinate, achenes, border-raised, 4- to 5-ribbed, resinous granuliferous. Leaves are very leafy, sessile or slightly petioled, cuneate at or flabelliform, narrowed at base, rounded apex or truncate, and 3–7 toothed (usually 3) silvery-canescent. Twigs are slender and gray or white at first and later gray to black. It can cause hay fever and has some medical uses.
Distribution: Dry and stoney soils on the arid plain of the Great Basin up to the timberline; also in British Columbia and Northern Mexico. It grows in Texas, New Mexico, Arizona, Colorado, California, North Dakota, Montana, Wyoming, and Washington.
Reproduction: Spreads and reestablishes by seed.
Control: Foliar-applied herbicides, such as 2, 4-D or soil-applied tebuthiuron.

10. Tarbush (*Flourensia cernua* DC.).
Description: Shrub 0.5 to 3 meters tall, highly branched, and leafy. Flowers are small, in groups of 12 to 20, yellow; fruit an achene, 0.6 cm or less long; leaves simple, alternate, persistent, elliptic to oblong or ovate to oval; margin entire; upper surface green, resinous; lower surface paler and glabrous; aromatic and hoplike odor associated with leaves. May be grazed during drought by sheep and deer, but branch tops, flowers, and fruit can be toxic (Welch and Hyden, 1996). It develops thick, persistent stands when in poorly managed rangeland. Twigs are light brown to gray (Vines, 1960).
Distribution: Tarbush is found in West Texas, New Mexico, Arizona, and Mexico.
Reproduction: It spreads by seeds and resists top removal by resprouting from a persistent crown. (Welch and Hyden, 1996).
Control: Soil-applied herbicides such as tebuthiuron and plowing will control tarbush.

11. Blackjack oak (*Quercus marilandica* Muenchh.).
Description: Blackjack oak is a shrub or round-topped symmetrical tree attaining a height of 18 meters and a trunk diameter of 0.6 meters. Flowers as catkins; fruit light brown acorns, closed one-third to two-thirds in a cup about 2 cm long; leaves obovate, usually with 3 lobes at apex; bark usually black, rough with grayish brown stiff twigs (Vines, 1960).

Distribution: Dry, sandy, sterile soils of central Texas, Oklahoma, and Arkansas; eastward through Louisiana to Florida, north to New York and west to Minnesota, Michigan, Illinois, and Kansas. Black-jack oak is usually found in close association with post oak, especially in the Post Oak Savannah of Texas. Although a serious management problem in some areas it serves as shade and cover for livestock and wildlife (Scifres, 1980; Vines, 1960).

Reproduction: By acorns and it readily sprouts from the trunk after top injury or removal.

Control: Soil-applied hexazinone and tebuthiuron are effective.

12. Black oak (*Quercus velutina* Lam.).

Description: Stout tree attaining a height of 30 meters with a spreading open crown. Bark is dark brownish black. Leaves are cut into usually 7 oblique lobes with sinuses of different depths. The species name *velutina* refers to the velvety pubescence of the lower leaf surface. The wood of black oak is used for rough lumber, crossties, and fuel. Flowers occur in April to May in staminate and pistillate catkins. Fruit matures in September and October as solitary or paired ovoid-oblong acorns 1.3 to 2.5 cm long with one-half to three-fourths of length enclosed in cup. Twigs are reddish brown (Vines, 1960).

Distribution: Often on poor, dry, sandy, heavy clay or gravelly soils in East Texas, Louisiana, Oklahoma, and Arkansas eastbound to Florida, north to Maine, and west to Ontario, Canada, and Wisconsin and Iowa (Vines, 1960).

Reproduction: The minimum seed-bearing age is 20 years, optimum is 40 to 75 years, and the maximum is 100 years. Good acorn crops are borne every 2 to 3 years with intervening light crops. Reproduction is by acorns.

Control: Soil-applied herbicides such as hexazinone and tebuthiuron.

13. Gambel oak (*Quercus gambelii* Nutt.).

Description: Very variable and widespread western species. Sometimes only a thicket-forming shrub or in favorable locations; can be a 15-meters-tall tree 0.6 meters in trunk diameter with a rounded crown. Flowers in May with young leaves in separate staminate and pistillate catkins. Fruit is solitary or several together, sessile or on tomentose peduncles. Acorns rounded, light brown, and glabrous, 1.3 to 1.9 cm long, enclosed about one-third to one-half in cup. Leaves are deciduous, oblong, obovate, oval, or elliptic, 6 to 15 cm long, and 3.8 to 8 cm wide with 5 to 9 lobes on margin. Twigs are reddish brown, pubescent to glabrous; older twigs are grayish brown. Bark is gray with deep fissures with small and appressed scales (Vines, 1960).

Distribution: At altitudes of 1200 to 2400 meters in western Texas;

northward to New Mexico, Arizona, Colorado, Utah, Nevada, and Wyoming; southward to Mexico in Coahuila and Chihuahua.
Reproduction: Reproduction is by acorns.
Control: The foliage is sometimes browsed by livestock, deer, and porcupine, and is sometimes controlled biologically by sheep and goats. Soil-active herbicides can be used.

14. Live oak (*Quercus virginiana* Mill.).
Description: Live oak is an evergreen tree or shrub. Flowers are staminate and pistillate borne in separate catkins on same tree and are 5 to 8 cm long, calyx yellow with 4 to 7 ovate lobes. Fruit are acorns on peduncles 0.6 to 10 cm long in clusters of 3 to 5. Acorns are brownish black, shiney, 0.8 to 1.3 cm long enclosed about one-half their length in the cup. Leaves are simple, alternate, dark green and lustrous above, paler and glabrous to pubesent beneath. The leaves are 5 to 13 cm long and 1.3 to 6.3 cm wide. Twigs are grayish brown, glabrous, slender, and rigid. Bark is dark brown to black (Vines, 1960).
Distribution: Live oak is usually found on sandy-loam soils, but occurs in heavier clays in Texas, Oklahoma, and Louisiana; east to Florida and north to Virginia (Vines, 1960).
Reproduction: Spreads by acorns and sometimes underground stems (rhizomes) and sometimes forms mottes. On the Gulf Coast of Texas it can assume a low, running-type growth form referred to as "running" live oak and highly restricts forage production in grazing lands.
Control: Soil-applied tebuthiuron is very effective.

15. Post oak (*Quercus stellata* Wangenh.).
Description: Shrub to tree to 23 meters tall. Flowers appear with leaves in March to May borne on the same tree in separate catkins 5 to 10 cm long, calyx yellow, hairy, 5-lobed; lobes acute, laciniately segmented. Fruit ripens in September to November, acorns oval or avoid to oblong, in pairs 1.3 to 1.9 cm long set in cup one-third to one-half their length. Leaves are simple, alternate, deciduous, oblong to obovate, blade 10 to 18 cm long and 8 to 10 cm wide, 5-lobed with deep rounded sinuses, lobes short and wide, obtuse or truncate at the apex, dark green, rough and glabrous above; paler and tomentose beneath. Twigs are brown and stout. Bark is gray to reddish brown (Vines, 1960).
Distribution: The Edward Plateau of Texas, adjacent Oklahoma and Arkansas; east to Florida, north to New England, and west to Iowa and Kansas.
Reproduction: Reproduces by acorns and can resprout from buds on the tree trunk.

Control: Soil-applied herbicides and some foliar growth regulator herbicides.

16. Sand shinnery oak (*Quercus havardii* Rydb.).
Description: Low shrub, hardly over 1 meter tall, forming thickets by underground rhizomes in deep, sandy soils. Rarely a small tree. Flowers in separate catkins. Fruit is a large acorn 1.3 to 2.5 cm long and 1.3 to 1.9 cm wide in cup. Leaves are alternate, deciduous, leathery, 1.9 to 10 cm long and 1.9 to 3.8 cm wide, oblong, coarsely toothed or lobed. Twigs are rounded or sulcate, gray to reddish brown. Bark is gray, smooth, or scaly (Vines, 1960). Acorns are sought by wildlife but are poisonous to livestock in the bud stage. The plant severely limits forage production (Welch and Hyden, 1996).
Distribution: Sandy plains of the Texas panhandle into eastern New Mexico.
Reproduction: By acorns and sprouts from the rhizomes.
Control: Deep plowing or goats are more effective than foliar-applied herbicides. Soil-applied herbicides such as tebuthiuron are effective (Welch and Hyden, 1996).

17. White oak (*Quercus alba* L.).
Description: Large tree to 45 meters tall with a broad, open head. Flowers appear in April to May, stamimate catkins about 7 cm long, calyx yellow, pubescent. Fruit ripens in September and October and is 1.9 to 2.5 cm long in cup. Leaves are alternate, simple, deciduous, oblong to obovate, 12 to 23 cm long, 7- to 11-lobed. Twigs are reddish brown to gray and bark is light gray to reddish brown (Vines, 1960).
Distribution: On bottom lands, rich uplands, and gravelly ridges in East Texas, Oklahoma, Arkansas, and Louisiana east to Florida, north to Maine, Ontario, Canada, and Minnesota, and west to Nebraska.
Reproduction: By acorns.
Control: Foliar and soil-applied herbicides.

18. One-seed Juniper [*Juniperus monosperma* (Engelm.) Sarg.].
Description: Evergreen tree sometimes 15 meters tall with a trunk to 1 meter in diameter, often several trunks. Flowers occur in March to April, dioecious, terminal, and axillary borne on branches of previous year. Fruit develops in September, fleshy, dark blue to brownish, 0.3 to 0.6 cm long. Seeds usually 1 to 2 sometimes extruded from fruit apex. Leaves minute grayish green, 0.15 to 0.3 cm long, opposite or in threes. Twigs are slender reddish brown. Bark is gray on trunks; ridges flattened and irregular. The fibrous bark is used for mats, saddles, and breechcloths. The wood is used for fuel and fence posts. The fruit is consumed by wildlife.
Distribution: At altitudes of 900 to 2000 meters in New Mexico, West

Texas, and Oklahoma, northward to northern Arizona, and south to Mexico (Vines, 1960).
Reproduction: Fruit persists 1 to 2 years. It is propagated by seed (Vines, 1960).
Control: Soil-applied herbicides.

19. Redberry juniper (*Juniperus pinchotii* Sudw.).
Description: Scraggly shrub or evergreen tree rarely over 8 meters tall. The numerous branches that spread are often close to the ground. Flowers are small cones dioecious, terminal or axillary on short branchlets. Fruit is a berrylike cone 0.6 to 0.8 cm long. Seed is avoid, obtuse at one end, and rounded at the other, solitary and 0.3 to 0.5 cm long. Leaves are aromatic, scalelike, yellowish green, appressed in ranks of two or three 0.15 to 0.3 cm long. Twigs are greenish; older twigs are red. Bark is reddish brown peeling off in shaggy longitudinal strips. Redberry juniper has low browse value but may furnish wildlife cover (Vines, 1960; Welch and Hyden, 1996).
Distribution: Dry hillsides and canyons of West Texas and the panhandle of Texas.
Reproduction: Spreads by seed but can sprout from the crown after top removal (Welch and Hyden, 1996).
Control: Chaining and cabling give acceptable control. Individual plant treatment with soil- and foliar-applied herbicides control redberry juniper.

20. Ashe or blue-berry juniper (*Juniperus ashei* Buchholz).
Description: Shrub or evergreen tree rarely over 8 meters tall; low-branched and trunk twisted. Flowers are minute, dioecious about 0.4 cm long; fruit is fleshy, berrylike cone about 0.6 cm long, blueish green, formed by compression of enlarged fleshy scales; leaves are long, scalelike, opposite. Twigs are gray to reddish and bark is gray to reddish brown, often in shaggy strips. The wood is used for fuel, posts, crossties, and woodenware. The foliage is occasionally consumed by sheep, goats, and deer. The fruit is eaten by wildlife, and wildlife receive cover from this tree (Vines, 1960; Welch and Hyden, 1996).
Distribution: Found in Texas, Arkansas, Oklahoma, and Missouri. It is common in central Texas but found southward and westward into Mexico and Guatemala (Vines, 1960).
Reproduction: Spreads only by seed; does not sprout from the crown after top removal.
Control: Prescribed fire and mechanical top removal are effective. Individual plant treatment with soil- and foliar-applied herbicides is effective (Welch and Hyden, 1996).

21. Eastern red cedar (*Juniperus virginiana* L.).
Description: Evergreen tree varying in shape, occasionally to 14 meters tall. Flower are dioecious; catkins of golden brown, female cones are fleshy purplish. Fruit is a berrylike cone, pale blue; leaves are scalelike or awl-shaped, sharp-pointed, glandless, and dark green. Twigs are reddish brown and the bark is light reddish brown, occasionally separating into long, fibrous strips. The wood is used for paneling, chests, pencils, poles, posts, and other uses. The aromatic nature of the wood makes it a good insect repellent. Cedar oil has various commercial uses (Vines, 1960).
Distribution: Eastern red cedar is found throughout the eastern United States, and west into Texas, Oklahoma, Arkansas, Nebraska, and North and South Dakota (Vines, 1960).
Reproduction: Spreads only by seed; does not sprout from the crown after top removal (Welch and Hyden, 1996).
Control: Prescribed fire and mechanical top removal are effective. Individual plant treatment with soil- and foliar-applied herbicides is effective.
22. Chamise (*Adenostoma fasciculatum* Hook. & Arn.).
Description: Evergreen shrubs with small needle-shaped and heathlike leaves about 0.6 cm long. White flowers in terminal panicles; fruit is an acheme. The plant can attain a height of 3 meters. The herbage is somewhat resinous and sweet-smelling (Bailey and Bailey, 1959).
Distribution: Southern California.
Reproduction: By seed, and can sprout from the stem and crown if top removed.
Control: Foliar- or soil-applied herbicides (Bovey, 1987).
23. Manzanita (*Arctostaphylos* spp.).
Description: The manzanitas are evergreen woody plants that vary from prostrate ground cover to small trees. Usually they have very crooked branches with smooth pinkish or reddish brown bark that may become shreddy on old branches. The leaves are simple and alternate. The small white or pinkish flowers are urn-shaped and borne in simple or compound clusters. The berrylike or drupelike fruit consist of several hard nutlets surrounded by a soft pulp. The manzanitas are highly ornamental plants but are not popular as such. They do not provide high-quality browse, but fruit is eaten by wildlife (Sampson and Jespersen, 1963).
Distribution: Of nearly 50 species of manzanita, 36 are native to the United States; the others are largely Mexican. California recognizes

43 species and 24 varieties of manzanita. Manzanita are constituents of the California chaparrel and are also found in Arizona, New Mexico. Texas, Colorado, Utah, and Oregon, as well as Mexico (Sampson and Jespersen, 1963).
Reproduction: Reproduction is by seed. Some manzanitas produce sprouts if the top is removed; others are nonsprouters (Sampson and Jespersen, 1963).
Control: Foliar spray during rapid spring growth with 2, 4-D amine (Bovey et al., 1984).

24. Rabbitbrush (*Chryothamnus* spp.).
Description: Rabbitbrushes are evergreen shrubs or subshrubs with smooth or tomentose foliage that is often resinous or aromatic. The leaves are simple, alternate, and entire. Heads have 4 to 20 yellow disk flowers that are bisexual and fertile. The heads are usually borne in panicles or cymes, rarely solitary. The achenes are rounded or somewhat angled, smooth to densely hairy. The pappus consists of dull white or brownish soft bristles. The genus *Chrysothamnus* contains 16 species and 41 subspecies (Call, 1991). The terminal portion of the flower stalks are browsed mostly in fall and winter (Sampson and Jespersen, 1963).
Distribution: Rabbitbrush is confined to North America, mainly in the western United States. Approximately 9 species and 18 varieties occur in California (Sampson and Jespersen, 1963).
Reproduction: By seed.
Control: Foliar sprays of 2,4-D ester, picloram, or picloram plus 2, 4-D when new growth appears (Bovey et al., 1984). Results with foliar- and soil-applied herbicides are variable (Call, 1991).

25. Snowberry (*Symphoicarpos* spp.).
Description: This genus includes low- or medium-height deciduous shrubs that often spread by suckers. The leaves are simple and opposite. The bisexual, bell-shaped, or tubular flowers are pink or white and borne in small axillary or terminal clusters. The fruits are roundish white berries. There are 10 to 15 variable species, all nature to North America. They are grazed by livestock and deer and provide wildlife cover (Sampson and Jespersen, 1963).
Distribution: Western United States and North America.
Reproduction: By seed.
Control: Foliar application with 2, 4-D or dichlorprop (Bovey, 1977).

26. Willow (*Salix* spp.).
Description: Willows vary in size from low creeping plants to large shrubs and small trees. Winter buds are covered by a single scale.

Leaves are mostly narrow. Willows have some value for browse for livestock and big game animals. Some are used in landscaping. There are many species of willow.
Distribution: Widespread in North America.
Reproduction: By seed, and produces sprouts if the top is removed.
Control: Foliar applications of 2, 4-D and other growth-regulator herbicides and soil-applied herbicides (Bovey, 1987).

27. Aspen poplar (*Populus tremuloides* Michx).
Description: Aspen poplar is a tree 6 to 12 meters tall with a trunk diameter of 38 to 50 cm. Rarely 30 meters tall and 1 meters in diameter. It usually has a long, slender trunk and narrow, rounded top. Bark is conspicuously whitened. Flowers occur in April and May on drooping catkins. Fruit is a capsule on short stalks, seed is obovoid, light brown, less than 10 mm long. Leaves are simple, alternate, deciduous, ovate and broad-ovate or reniform, 2.5 to 10 cm long. Twigs are reddish brown to gray and slender. Bark is thin, smooth, greenish to gray or white marked with rows of leaf scars. Foliage is consumed by livestock, deer, and elk (Simpson and Jespersen, 1963; Vines, 1960).
Distribution: Occurs from sea level up to 3000 meters, widely distributed in North America.
Reproduction: The tree spreads by root sprouts and seed.
Control: Foliar- and soil-applied herbicides.

28. Yucca (*Yucca* spp.).
Description: About 30 bayonet-leaved, showy flowered species. They are stemless or rising to stature of small trees. The leaves are stiff and long-pointed, often toothed or fibrallose on margins; mostly in rosettes at the surface of the ground or ends of trunk or branches. Flowers are cup-shaped or saucer-shaped with waxy texture, white cream or violet, opening and fragrant at night (Vines, 1960).
Distribution: Tablelands of Mexico and northward and in the West Indies and eastern United States.
Reproduction: By seed and root stock.
Control: Individual plant treatment with foliar sprays of triclopyr (Welch, 1997).

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2

History and Development of Woody Plant Management

I. INTRODUCTION

A comprehensive review of the *Journal of Range Management* indicated that there were far more scientific papers published on chemical woody plant control than any other method in the last 50 years (Table 1). This is true regardless of the time period investigated. Even in the last 10-year period (1990 to 2000) more papers were published about using herbicides than about using fire or biological or mechanical means. Economic constraints and governmental restrictions have been particularly operative against chemicals, beginning in the 1970s. More than 54 papers were published on chemical brush control in each of the two decades from 1970 to 1990. Even during the 1980s, when prescribed burning was reemphasized, there were still more than twice as many papers published about using herbicides (55) versus fire (26). These numbers do not include chemicals used in integrated brush management systems (IBMS) or in papers in which several methods were compared (Table 1). It clearly shows the importance of herbicides or the perceived importance of herbicides in woody plant control, whether used alone or with other methods.

It is interesting that all methods were researched and published in each 10-year period from 1949 to 2000. Herbicide use was the most researched method, then fire, mechanical, and biological control, in descending order. The number of papers on fire and biological control was fairly evenly distributed between each 10-year period except for the small increase for fire in the 1980s.

More than twice as many papers were published about fire than about biological control over the 50-year period, although in the 1990s paper numbers

TABLE 1 The Number of Scientific Papers Dealing with Different Woody Plant Control Methods Published in the *Journal of Range Management* (1949–2000)

	Control method						
Years	Chem.	Fire	Bioc.	Mech.	IBM	Several	Reveg.
1949–1959	31	18	5	8	4	7	7
1960–1969	37	13	7	8	1	1	3
1970–1979	59	15	6	18	5	1	4
1980–1989	55	26	7	19	4	8	3
1990–1999	23	10	9	15	3	0	4
Total	205	82	34	68	17	17	21

Note: Chem. = chemical control; Fire = prescribed burning or wildfire; Bioc. = biological control; Mech. = mechanical control; IBM = integrated brush management; Several = several control methods used but not IBM; Reveg. = reseeding and/or revegetation of range and/or forest land. A few papers listed under fire do not specifically include woody vegetation, but emphasize the rangeland environment.
Source: *Journal of Range Management*, 50 years of research on woody plant control.

were similar (10 versus 9). In the 1970s to the 1990s papers on mechanical brush control doubled, compared to the 1950s and 1960s.

We think of IBMS as a concept developed in the 1980s but such concepts had their beginning much earlier (Table 1), even though they were not called by the same name. The attempts at comparing several single brush control methods on the same site or on the woody species (or combining some methods) were merely a search for the most economical and effective method(s).

Reseeding and revegetation is not a control method, but should be part of the brush control effort to restore desirable forage and grazing opportunity, as well as to stabilize the soil. A vigorous forb and grass stand should discourage weed and brush invasion or reinvasion, as indicated in Chapter 11.

As stated, one woody plant control method may be combined with another for the most efficient and economical method of woody plant control and maintenance. Two control methods are usually not applied in the same year, but may be administered a year or two later or used to maintain control every few years (e.g., the use of prescribed burning following herbicides).

II. FIRE

A. Early History

Fire has been a tool for woody plant control and has influenced woody and herbaceous species composition on a given site for centuries. Stokes (1980) indicated that it is possible to use tree rings—dendrochronology—to study the fire history of a given area. Ahlstrand (1980) studied fire-scarred southwestern white pine (*Pinus strobiformis*) cross sections from a 1700-hectare (ha) area in the Guadalupe mountains in New Mexico. At least 71 fires have occurred on the site since 1554. From 1696 to 1922 the mean interval between major fires was 17.6 years. No samples were scarred after 1922, coinciding with occupancy and use patterns in the mountains during the past century. In contrast, Arno and Davis (1980) gathered data on the fire history for the western red cedar/hemlock forests. On upland habitat types fires of variable intensities generally occurred at 50- to 150-year intervals, often having a major effect on forest succession. On wet and subalpen habitat types, fires were infrequent and generally small. The average interval between successive fires in Yellowstone National Park is estimated to be greater than or equal to 300 years (Romme, 1980).

Prior to 1860 the maximum individual fire intervals usually did not exceed 35 years in the forests of western Montana (Barrett, 1980). Indians set fires for a number of reasons, including weed and brush control, improved berry production, forage production, hunting, camping, and travel. During the period from 1861 to 1910 Indian fires still occurred in western Montana, but to a much lesser degree. Prospectors and others caused many fires in the late 1800s, but after 1910 fire suppression attempted to eliminate all fires in the region. In the McCalla Creek area fires occurred on an average of every 8.6 years, but sample trees have not recorded a fire for the last 91 years (Barrett, 1980).

Madany and West (1980) developed a fire chronology for the last 480 years from 119 partial cross sections of fire-scarred ponderosa pine. Large fires (>400 ha) occurred nearly every 3 years prior to 1881 on the Horse Pasture Plateau in Utah. A sharp decline in fire frequency began thereafter, some 40 years before the area was obtained by the National Park Service. Changes in land use triggered fire decline.

Lorimer (1980) used records from early government land surveys to estimate the proportion of stands killed by fire in a 15- to 25-year period preceding the survey for vast areas of presettlement forest in eastern North America. Identification of postfire stands was possible in some regions. In South Florida historic fires were identified by charcoal deposits and endemic plants (Taylor, 1980). Lightning caused fires, probably occurring during drought cycles of about 8 years. The fires were several thousand ha in size and burned most fire-adapted vegetation every two cycles.

Wright and Bailey (1982) indicated that there are no reliable historical records of fire frequency in the Great Plains grassland because there are no trees to carry fire scars from which to estimate fire frequency. Fire frequency was high because explorers and settlers were concerned about the danger of prairie fires. We can also extrapolate fire frequency data for grasslands from forests having grassland understories, such as pondersosa pine (*Pinus ponderosa*) in the western

United States and longleaf pine (*Pinus palustris*) in the southeastern United States. Fire frequency of grasslands has been estimated at 5 to 10 years and up to 30 years where topography is dissected with breaks and rivers such as the rolling plains and Edwards Plateau of Texas (Wright and Bailey, 1982). Wright and Bailey (1982) suggested that natural fire every 15 to 30 years in the southern mixed prairie has significantly reduced shrubs and trees, although drought and biotic factors were also dominant factors in maintaining North American grasslands.

These examples and many others given at the Fire History Workshop in Tucson, Arizona, in 1980 indicated that fire has played a very significant role for centuries in the control of woody vegetation (e.g., control of underbrush in conifers) and influenced the type and frequency of vegetation that occurs in a given area. There was great variation in fire frequency and the resulting development of vegetation within the same area, depending upon the type of original vegetation, topography, soil type, climate, and many other factors. In many areas during the last 100 years or more, after settlement land use has changed fire frequency, and in many areas fire prevention is practiced.

B. Recent History

Fire continued to have a major impact on North American plant communities after the arrival of Europeans because of lightning, deliberate use of fires, and carelessness (Wright and Bailey, 1982). European-trained foresters indicated that fire was bad because it killed trees, and fire suppression was strictly practiced starting about the turn of the century. Wright and Bailey (1982) cite a report by Leopold et al. (1963a) as a turning point in informing the public of the benefits of using fire in the national parks. Without fire bad effects included excessive fuel buildups, stagnant young pine trees, dense understories of shrubs and trees, catastrophic stand-replacing fires, less diversity in wildlife, and devastating fires that cannot be readily controlled. The benefits of fire included fuel reduction, seedbed preparation, disease control, thinning, suppression of shrubs, removal of litter, increased herbage yield, increased availability of forage, and increased wildlife (Wright and Bailey, 1982).

Since fire was a natural component of plant community evolution other individuals also supported natural fire where possible. For example, Stewart (1951) indicated that although the influence of burning on vegetation is well known, it is not always fully understood. What European settlers observed in vegetation in North America was significantly influenced by fire since its use was widespread and probably frequent.

Aside from fires set by lightning, Indian burning in the United States was almost universal (Stewart, 1951). More than 200 references to Indians setting fire to vegetation in aboriginal times indicated all major geographic and cultured areas were burned. Once started, fires were allowed to burn unchecked until they burned out or were extinguished by natural causes. Reasons for burning were many, including brush control and fire for personal safety or protection of habitations. Fire was sometimes directed toward enemies and away from retreating Indians (Stewart, 1951). Fires were started to aid in hunting, to improve pasturage, to allow for the growth of berry bushes, tobacco plants, and other crop space, to facilitate travel, and to facilitate offense and defense in war.

Stewart (1951) cites southeastern and south Texas as an example of an extensive region now covered with mesquite and other woody plants that was once open prairie, probably because of extensive burning by Indians. When livestock grazing increased, however, woody plants began to increase. Extensive grazing left insufficient fuel to produce fires hot enough to kill trees. Many areas in California now covered with chaparral have a similar history.

Stewart (1951) indicated that the origin of the tall-grass prairies is difficult to explain, but fire may have played a primary role. The absence of charred roots and stumps has been regarded by some to indicate that forests never existed on prairie land in aboriginal times. Others have suggested that fires may have been so intense and rapid—frequently aided by high winds—that trees and shrubs were never allowed to establish.

In contrast to the benefits indicated by Stewart (1951), the U.S. Forest Service indicated that in the decade that ended in 1950 nearly 2 million forest fires occurred in the United States (Forest Service, 1954). They occurred at a rate of about 500 per day, and burned an average of 8.5 million ha each year, an area larger than Maine. The cost to timber and property in 1950 was estimated at nearly $400 million, with scores of human lives lost. At the same time this bulletin describes beneficial fire uses, such as prescribed burning to aid the regeneration of longleaf pine for weed and brush control in the southern pine region (Forest Service, 1954). It was also used to remove heavy ground cover to reduce destructive wildfire. In the Northwest, burning was used at a safe season to eliminate logging slash and debris.

It therefore became apparent that some areas needed to be protected from fire, while other areas benefited from fire. Sampson (1957) therefore proposed a change in burning terminology as follows:

Management burning. A general term covering the deliberate use of fire on land for the purpose of removing unwanted plant material. Management burning includes convenience burning, control burning, and prescribed burning.

Convenience burning. The simplest form of management burning, in which the only elements planned are the time and place of firing.

Control burning. The application of fire to a preselected land area according to a definite plan, utilizing control forces adequate to confine the fire to the area selected.

Prescribed burning. The ultimate in careful use of fire as a tool for land clearing, involving: the use of fire as a silvicultural tool—burning under rigid restrictions with respect to the humidity and the temperature of the air and fuel; burning within rigidly specified ground limits; burning with the fire under control at all times; and not burning when weather or other conditions are unfavorable at the time planned for firing.

Apparently these definitions were adopted, since similar definitions are indicated by Vallentine (1989).

Wright and Bailey (1982) indicated that in the 1960s biologists of all disciplines began taking a constructive view of fire in North America. Fire reintroduction as a natural force began in the Southeast and Northeast and spread on a limited scale to all North America. Interest in fire accelerated because alternative methods such as herbicides and mechanical and biological means were environmentally unacceptable or ineffective. In the case of insect and disease outbreaks, alternatives to fire have sometimes been unsatisfactory. Further, with 80 years of fire protection in our western forests, understory growth and the resulting wildfire are difficult to control. These massive fuel buildups must be removed in forests by highly trained personnel for maximum safety and reduced cost. Prescribed burning on private and public lands could restore forest, rangeland, and wildlife habitat instead of wasting vast funds on fighting fire.

McCord and McMurphy (1967) indicated that prairie fires burn thousands of grass and woodland ha in Oklahoma every year. In the early 1960s they indicated that most fires were accidental, but some were purposely burned, with some beneficial and some detrimental effects. Most accidental fires occur under dry conditions, damaging rangeland forbs and grasses. Annual late spring burning reduced forage about 10%, but winter burning left soil bare and subject to erosion, and reduced forage yield about 20%. Burned areas needed protection from overgrazing. Fire can increase seed production of desirable native grasses, and can control (spring burn) many cool-season weeds. It can also cause some undesirable woody species to sprout profusely, such as smooth sumac, blackjack, and post oak. Spring burns prior to the initiation of new growth may reduce forage yield, but the increase in steer gain has been about 6 to 9 kg/ha of beef annually.

In the mid-1970s Wright (1974) indicated that few land managers had the training or courage to conduct a burn. Most were exposed to catastrophic fires, which are untimely, have undesirable effects, and are frightening. Prescribed burning has many uses in the management of forests, chaparral, grasslands, watersheds, and wildlife. To minimize harmful effects, fire should never be used during extended dry periods; burns should always take place when the soil is damp or wet (Wright, 1974). Moreover, the user should be an experienced professional with a thorough knowledge of ecosystems, weather, and fire behavior.

Kilgore (1976) stated that many of the present wildlife problems began when attempting to ban all fires from forests, yet control of wildfire was essential in the late nineteenth century since forest resources were being destroyed by careless logging and catastrophic fires (Forest Service, 1954). Two such wildfires were Peshtigo in Wisconsin in 1871, which killed 150 people and burned 1.2 million acres (0.5 million ha), and Hinkley in Minnesota in 1894, which killed 400 people and burned an undetermined area of land (Kilgore, 1976). Such events set the stage for rigid fire-control policies. Efforts to more effectively control forest fires in America began with the founding of such organizations as the American Forestry Association in 1875. The policy to suppress fires in national parks began in Yellowstone in 1886 and was incorporated in the National Park Act of 1916 (Agee, 1974). The establishment of the Forest Reserves in 1891 and the Forest Service soon after had public support (Clepper, 1975). Fire suppression was based on claims that fire of any kind damaged trees and killed seedlings, destroyed forage plants, depleted soil fertility, promoted floods, droughts, and erosion, and destroyed bird and animal habitat (Komarek, 1973).

Early research in the South and West changed government policy and public opinion about prescribed burning. The southern fire scientists showed that controlled burning can be beneficial to longleaf pine, cattle, and quail, while total fire exclusion in the South led to considerable problems, including a tremendous increase in fuel and fire hazards (Kilgore, 1976). Not until 1943 did the weight of this evidence bring about adoption of a prescribed burning policy for southern forests (Shiff, 1962). A similar challenge was raised in the West by the combined research and experimental management efforts of two foresters at the Bureau of Indian Affairs (BIA) and a forestry professor at the University of California (Kilgore, 1976). Conclusions from their studies indicated that vegetation in the ponderosa pine forests of the western United States developed in nature with frequent light fires, that fire exclusion has resulted in extreme fire hazards today, and that prescribed burning by means of light fires can reduce fuels while simulating other ecological impacts of natural burning (Kilgore, 1976).

As indicated by Wright and Bailey (1982) earlier in this chapter, the Leopold report was the document of greatest significance to present National Park Service fire policy (Kilgore, 1976). The report was presented at the North American Wildlife and Natural Resource Conference in 1963 and suggested that "a reasonable illusion of primitive America would be recreated using the utmost in skill, judgment, and ecologic sensitivity" (Leopold et al., 1963b). Data in this report were largely adopted as National Park Service policy in 1968, bringing about a major reorientation in attitudes toward fire suppression (Kilgore, 1976).

As early as 1976 the U.S. Forest Service completed a large-scale computer model for evaluating alternative fire-management plans (Davis and Irwin, 1976).

The model—called FOCUS (fire operational characteristics using simulation)—has been widely tested and became operational in 1976. FOCUS can help fire management organizations evaluate the performance of alternative plans and their impact on the fire protection job. The model can also be applied to fire-related environments, economic and political problems, and overall land-use planning.

In several western national forests, the Forest Service was heavily criticized by the public after the 1979 fire season for allowing certain forest fires to burn rather than extinguishing them (Fischer 1980). Fischer (1980) stated that current fire-management policy requires an appropriate suppression action to be taken in each fire. The potential resource damage by fire is weighed against potential benefits and cost. If the analysis indicates high escape potential for serious resource damage an all-out suppression effort is launched; however, if potential damage is low, the manager may elect to limit suppression. The fire is allowed to burn under preselected conditions, and the use of prescribed burning (planned) is encouraged. Fischer (1980) indicated that early results in the northern region illustrated by events of Forest Services fire-management policy are encouraging but by no means conclusive. The ultimate success or failure of fire management will most likely depend upon how well fire managers master improved fire-management techniques and how accurately they can predict long-term fire effects on forest and rangeland resources.

Controversy still exists for chaparral management in southern California, even with prescribed burning (Laisz and Wilson, 1980). Other means are also needed in addition to prescribed burning since frequent burns on steep slopes can degrade the soils and flora and cause serious off-site damage.

C. Fire History by Location and Vegetation Type

1. Great Plains

Wright and Bailey (1980) indicated that fires were prevalent in grasslands and climate was the major factor in their maintenance. Fire frequency probably varied from 5 to 10 years on level to rolling topography and from 15 to 30 years on rougher terrain. In the short-grass prairie fires do not benefit grasses but can be used to control small juniper and cactus. In the mixed and tallgrass prairies prescribed burning can control undesirable trees and shrubs, burn debris, increase herbage yields, can increase coarse grass utilization and available forage, can improve wildlife habitat, and can control exotic, cool-season grasses.

2. Semidesert Grass-Shrub Type

Historical evidence indicates that fires were present in the semidesert grass-shrub type in southeastern Arizona, but there is less supportive evidence for southern New Mexico and southwestern Texas (Wright, 1980). The change from grass to brush in the last 100 years was due to a combination of factors related to the intensification of grazing. During dry seasons that follow 1 or 2 years of above-average summer precipitation, fire can be used to control burroweed, cactus, broom snakeweed, creosote bush, and young mesquite plants. False mesquite, velvet-pod minosa, wright baccharis, and fourwing saltbush recover quickly after burning. Natural fire frequency was about 10 years for southeastern Arizona, but probably less than every 10 years in southern New Mexico and southwestern Texas.

3. Sagebrush-Grass and Pinyon-Juniper

In sagebrush-grass communities fire was less frequent than in the grasslands of the Great Plains or in the semidesert grass-shrub type (Wright et al., 1979). In Yellowstone National Park estimates were 20 to 25 years but was probably about every 50 years based on the vigorous response of horseweed (*Tetradymia canescens*) and rabbitbrush to fire. Although it is generally known how most shrubs and herbaceous plants respond to fire in the sagebrush-grass communities more data are needed on bluebunch wheatgrass, Idaho fescue, big sagebrush, and bitterbrush (Wright et al., 1979).

The pinyon-juniper association covers 17 to 31 million ha in western North America. The historic role of fire in controlling the distribution of pinyon-juniper cannot be separated from the effects of drought and competition from grass (Wright et al., 1979). Fires every 10 to 30 years probably kept junipers restricted to shallow, rocky soils and rough topography, but for the last 90 years heavy grazing has reduced grass competition as well as fuel for fire that checked pinyon and juniper invasion.

4. Chaparral and Oakbrush

a. California Chaparral California chaparral consists of about 3.5 million ha in California and south-central Oregon (Wright and Bailey, 1982). When woody vegetation reaches 20 years of age dead fuels become great enough to support big fires under adverse conditions. As a consequence, the recurrence interval of large fires (>2000 ha) is 20 to 40 years, but most fires larger than 12,000 ha occur in brush 30 years old or older. At high elevations (1200 meters) on northern aspects, fire frequency in Eastwood manzanita (*Arctostaphylos glandulosa*) chaparral may be every 50 to 100 years.

b. Arizona Chaparral Arizona chaparral burns periodically, but has a lower fire frequency than California chaparral (Wright and Bailey, 1982).

c. Oak Brush The oak-brush areas are just above the pinyon-juniper zone in the central Rocky Mountains and have a fire frequency of 50 to 100 years (Wright and Bailey, 1982). Most fires in Gambel oak (*Quercus gambelii*) occur after a buildup of litter and mulch under the shrub mottes during dry periods (Vallentine, 1989). Most fires are spotty and irregular.

5. Ponderosa Pine

Fire frequency varies considerably, depending upon region and site (Wright and Bailey, 1982). In Arizona and New Mexico frequency for climax and seral communities was between 5 and 12 years. The frequency was 10 years in California and the Blue Mountains of eastern Oregon, but ranged from 2 to 23 years in the Sierra Nevada. In the Bitterroot National Forest of eastern Idaho and western Montana fire frequency averaged from 6 to 11 years for climax stands and 7 to 19 years for ponderosa pine that was seral to Douglas fir (*Pseudotsuga menziesii*).

6. Douglas Fir and Associated Communities

Low-frequency, high-intensity crown fires were the norm before settlement in West Coast coniferous forests (Wright and Bailey, 1982). Fires of 50,000 to 1 million ha were common (Martin et al., 1976). Lower-intensity surface fires were frequent, but generally burned over relatively small areas. Fire frequency in West Coast forests of Douglas fir has been estimated from 150 to over 500 years (Franklin et al., 1981). The free-fire interval in western hemlock forests has been estimated at <150 years (Martin et al., 1976). Pacific silver fir requires a fire-return interval of 700 to 800 years to maintain stand dominance (Schmidt, 1957).

The fire history of the northern Rocky Mountains and adjacent plateaus east of the Cascade range is very varied. Fire-return intervals varied from greater than 500 years in moist subalpine forests to about 6 years in dry forest on grassland of valleys and lower exposed slopes (Wright and Bailey, 1982). Both crown surface fires occurred. Fire severity varied with vegetation type, fuel, weather, and topography.

In the central and southern Rocky Mountains most forests established after fire disturbance (Wright and Bailey, 1982). Before settlement fire maintained open stands of Douglas fir every 25 to 100 years.

7. Southeastern Forest

Historical evidence suggests that fire was a common and widespread occurrence across the South (Harper, 1962). Fire was generally not accepted as a tool in the southeast United States until 50 years after it was first recommended as a management tool by Chapman in 1909, however (Riebold, 1971).

8. Other Forested Regions

Other forested regions mentioned by Wright and Bailey (1982) included the spruce-fire community, in which fires are rare. Fire, however, is a natural force that can influence regeneration of all spruce species in the northwestern and northeastern United States. Sitka spruce occurs in a narrow zone along the Pacific coast of North America and includes trees of western hemlock and western red cedar with some fir species. Prescribed fire is seldom used in the spruce-hemlock type because of the wet climate.

The Engelman spruce (*Picea engelmannii*) is associated with subalpine fir (*Abies lasiocarpa*) and occurs throughout the Rockies. These species are susceptible to severe damage by fire during drought years, but do recover (Wright and Bailey, 1982). Fire can be used as a silvicultural tool if done wisely.

Red spruce (*Picea rubens*) grows from sea level to 1370 meters in the northeast United States. Many other tree species grow with it. Fires occur in red spruce, but are rare, distructive, and of little silvicultrual valve.

Fire was used to maintain stands of red pine (*Pinus resinosa*) and eastern white pine (*Pinus strobuis*) in southern Canada, the lake states, New England, and the southern Appalachians (Wright and Bailey, 1982). Fire frequency has been documented for red pine between 29 to 37 years. Fires have been documented for both red and white pines through historical records, and since they are natural "fire types," controlled burning can be used in their management.

Coastal redwood (*Sequoia sempervirens*) is a climax forest in which redwood is sustained by low rates of reproduction in tree replacement (Wright and Bailey, 1982). It does not depend upon recurrent fires for its status, but is tolerant of low-intensity fire. On mesic sites fire frequency was from 200- to 500-year intervals, and inland and at higher elevations was from 50- to 100-year intervals. Where fires are more frequent, Douglas fir, a redwood associate, appears more frequently. Inland fires occurred about every 25 years.

Giant sequoias (*Sequoiadendron giganteum*) do not sprout; they depend upon seed for regeneration. Fire frequency averaged every 10 to 18 years before 1875, depending upon the site. Fire provided a mineral seedbed for regeneration, recycling of nutrients, and removal of thickets of climax species, such as incense cedar (*Calocedrus decurrens*) and white fir.

D. Prescribed Burning on Rangelands

Since this report is concerned with woody plant management we will discuss the effect of fire on our major woody weed species and associated plants in some of the vegetation types mentioned earlier in this chapter.

1. Sagebrush-Grass

Pechanec and Stewart (1944) provided research in southeastern Idaho that indicated increased grazing capacity averaged 69% on experimental burns compared to unburned areas, with perennial grass and weed increases of 60%. Big sagebrush was completely killed, and only 6% of three-tip sagebrush sprouted. Soil losses were minimal, and range, with little understory of perennial grasses and weeds, should not be burned. Valuable plants, however, such as Idaho fescue, bitterbrush, and some shrubby weeds, were badly damaged. In contrast to the benefits from planned burning, accidental or haphazard burning nearly always produced great damage and loss of soil by erosion and forage. Pechanec and Stewart (1944) recommended burning only where sagebrush is dense, where there are firm and gentle slopes, where fire-resistant perennial grasses and weeds are abundant, and where principal use of the range is for livestock grazing. Severely damaged, slightly damaged, and undamaged species are shown in Table 2.

Table 2 Plant Damage from Experimental Burns on Southeastern Idaho Rangeland

Severely damaged species	
Idaho fescue	*Hoary phlox*
Threadleaf sedge	Saskatoon serviceberry
Low pussytoes	Big sagebrush
Littleleaf pussytoes	Threetip sagebrush
Uinta sandwort	Granite gilia
Englemann fleabane	Broom snakeweed
Wyeth eriogonum	*Antelope bitterbrush*
Mat eriogonum	
Slightly damaged species	
Bluebunch wheatgrass	Timber poisonvetch
Prairie Junegrass	*Milkvetch*
Indian ricegrass	*Northwestern painted-cup*
Sandberg bluegrass	*Tapertip hawksbeard*
Nevada bluegrass	Sticky geranium
Cusick bluegrass	*Tailcup lupine*
Subalpine needlegrass	*Royal penstemon*
Needle-and-thread	Munro globemallow
Thurber needlegrass	
Undamaged species	
Crested wheatgrass	Velvet lupine
**Thickspike wheatgrass*	**Stansbury phlox*
*Bluestem wheatgrass	*Flaxleaf plainsmustard
Cheatgrass brome	*Lambstongue groundsel
*Purple pinegrass	Foothill deathcamas
**Douglas sedge*	*Downy rabbitbrush*
*Western yarrow	Spineless gray horsebrush
Wild onion	*Orange arnica
Arrowleaf balsamroot	*Common comandra
**Purpledaisy fleabane*	

Note: Names in italics are important because of their abundance and moderate to high palatability. Those undamaged species marked with an asterisk are spread by rootstocks or root shoots.

Nonresistant plants may require years of careful management for recovery. Pechanec and Stewart (1944) suggested when, where, and how to burn.

Blaisdell (1953) considered big sagebrush a serious management problem in extensive areas of the west. Blaisdell (1953) indicated that all grasses were injured by burning in the upper Snake River region of Idaho, but thickspike wheatgrass, plains reedgrass, and bluebunch wheatgrass recovered rapidly. After 12 to 15 years burned areas produced as much or more herbage as unburned areas even though other grasses were shown to recover. Forbs were injured, but by 3 years more herbage was produced on burned versus unburned range. Rabbitbrush and horsebrush quickly regained or surpassed their original size. The estimated grazing capacity of burned range was 40% greater than unburned in Fremont County and 100% in Clark County, Idaho.

Blaisdell and Mueggler (1956) found that bitterbrush [*Purshia tridentata* (Pursh) DC.], a widely distributed forage shrub in the western United States, commonly resprouted and recovered after the burning of a big sagebrush range or mechanical top removal. Some mortality occurred from burning or top removal. One big problem in more recent times in the Snake River plains is that cheatgrass (*Bromus tectorum L.*), an introduced annual, increases with fire frequencies (to less than every 5 years) by creating a more continuous fuelbed (Whisenant, 1990). More frequent fire and reduced patchiness greatly retard normal vegetation replacement. Presettlement fire frequency was probably between 60 and 110 years. Reducing fire frequency and fire size on these areas should be a primary management objective.

In Utah, Ralphs et al. (1975) indicated that millions of ha of western rangeland are dominated by stands of sagebrush and juniper. Prescribed burning is an efficient and economical range-management tool for these low-value brush species. Late summer, fall, or spring burns are made, but adequate fuel breaks and fire-suppression equipment must be available to prevent escape of the fire. Ralphs et al. (1975) list the effects of fire on foothill plants based on usability for livestock forage (Table 3).

In Wyoming, Smith et al. (1985) found that big sagebrush was killed where uniform fire spread occurred. Green rabbitbrush (*Chrysothamnus viscidiflorus*) and horsebrush (*Tetradymia canesecens*) resprouted and increased in production but did not increase in density. Greasewood (*Sareobatus vermiculatus*) had high mortality. On a more mesic site, aspen, snowberry, and serviceberry resprouted, while bitterbrush did not. Dominant grasses tended to increase. Rhizomatous wheatgrass outperformed other species. Good follow-up management is necessary for the best vegetation responses.

2. Juniper

Burkhardt and Tisdale (1976) indicated that the invasion of western juniper (*Juniperus occidentalis* subsp. *occidentalis*) into vegetation dominated by mountain big sagebrush and perennial bunchgrass on the Owyhee Plateau of southeast

TABLE 3 Foothill Plant Damage from Fire in Sagebrush- and Juniper-Dominated Stands in Utah

Severely damaged	Moderately damaged	Slightly damaged
Desirable	*Desirable*	*Desirable*
Bitterbrush	Bluebunch wheatgrass	Arrowleaf balsamroot
Cliffrose	Indian paintbrush	Crested wheatgrass
Curlleaf mountain mahogany	Indian ricegrass	Douglas sedge
Eriogonum	Needle-and-thread	Sandberg bluegrass
Idaho fescue	Nevada bluegrass	Serviceberry
Threadleaf sedge	Penstemon	Snowberry
	Prairie Junegrass	True mountain mahogany
Undesirable	Squirreltail	Western wheatgrass
Sagebrush	Thurber needlegrass	Yarrow
Juniper		
Pinyon pine	*Undesirable*	*Undesirable*
Pussytoes	Tailcup lupine	Broom snakeweed
		Cheatgrass
		Deathcamas
		Horsebrush
		Rabbitbrush
		Velvet lupine

Idaho appears to be directly related to the cessation of periodic fire. Juniper seedlings became established most readily on areas supporting well-developed herbaceous and shrubby vegetation. Evidence from adjacent climax juniper stands indicated that fires were frequent for at least several hundred years preceding settlement.

Prescribed burning benefits became evident in the pinyon (*Pinus monophylla*) juniper (*Juniperus osteosperma*) stands in Utah and Nevada (Ralphs et al., 1975; Blackburn and Bruner, 1975; Wright et al., 1979) in the late 1960s and early 1970s. Blackburn and Bruner (1975) indicated in Nevada the various prescribed pinyon-juniper burnings were categorized into 1) burning slash and debris, 2) burning individual trees, 3) burning grassland or sagebrush/grassland to kill invading trees, and 4) using broadcast burning when the fire hazard is low and impact is minimal on vegetation, and using natural firebreaks to control fire.

Wright et al. (1979) indicated that the pinyon-juniper association covers from 17 to 31 million ha in western North America, from the east slope of the Sierra Nevada, eastward throughout the mountains of the Great Basin in Nevada and Utah, and on both flanks of the Rocky Mountains in Colorado, as well as on the mesas of the Colorado Plateau and the interior valley. It also occurs southward into Arizona, New Mexico, and northern Mexico. Dominant tree species are Utah juniper (*Juniperus osterosperma*), one-seeded juniper (*J. monosperma*), Rocky Mountain juniper (*J. seopulorum*), Alligator juniper (*J. deppeana*), doubleleaf pinyon (*Pinus edulis*), and singleleaf pinyon (*P. monophylla*). Dense stands of juniper alone that join the pinyon-juniper woodlands extend further north, into eastern Oregon, southern Idaho, and Wyoming.

Wright et al. (1979) indicated that in addition to fire, drought and competition from other vegetation have played a role in controlling the pinyon-juniper distribution. For the last 90 years, however, heavy livestock grazing has reduced grass competition as well as fuel for fires. Reduced competition from grasses has permitted pinyon and juniper to invade adjacent communities rapidly.

Experimental burns by Jameson (1962) in 1956 in the Coconino National Forest in Arizona of galleta [*Hilaria Jamesii* (Torr.) Benth.] and black grama [*Bouteloua eriopoda* (Torr.) Torr.] grasslands and a wildfire in June of 1956 in the Wupalki National Monument indicated that fires caused considerable damage to small juniper (*J. monosperma*) trees (70 to 100% kill), but less damage to larger trees (30 to 40% kill). Kill on larger trees (>1.2 m tall) depended upon ample fuel beneath the tree and correct wind direction (Jameson, 1962; Wright et al., 1979). Trees in closed stands of pinyon-juniper with no grass or sagebrush in the understory are difficult to kill because fires do not carry easily (Blackburn and Bruner, 1975).

Bunting (1996) indicated that fire history studies for juniper-dominated areas show that a fire-free interval of 50 years or less would probably have checked juniper invasion during the pristine period. The number of fire ignitions currently received do not adequately check juniper, given the dissected nature of topography and the discontinuous fuels of these areas, however. Kittams (1972) studied 10 burn areas (wildfire) in the Carlsbad Caverns National Park, New Mexico, in the Chihuahuan Desert region. The response of different woody and herbaceous species to fire was recorded as shown in Table 4.

Although redberry juniper (*J. pinchotii*), alligator juniper (*J. deppeana*), earyleaf oak (*Quercus undulata*), and low Mohr's oak (*Q. mobriana*) were not controlled by hot burns, the investigator concluded that fires recurring as often as every 10 years would probably maintain the grassland aspect of the burned sites. Deer-forage quality would be increased by rejuvenation of hairy mountain mahogany and oak and natural reseeding of ceanothus.

In other studies Ahlstrand (1982) found that the coverage and frequency of redberry juniper and whiteball acacia (*Acacia texensis*) were lower, while frequencies of catclaw mimosa (*Mimosa biuncifera*) and skeleton goldeneye (*Viguiera stenoloba*) were higher on burned sites compared to unburned paired plants on the Chihuahuan Desert. Other data on plants species agree with Kittams's (1972) data. Sleuter and Wright (1983) indicated that burning intervals of 7 to 20 years should prevent new redberry juniper from becoming established in north and west Texas. These burning intervals should top-kill established plants and

Table 4 Effect of Fire on Vegetation, Carlsbad Caverns National Park

Plant	Burns hot	Usually killed by fire	Types of sprouts after fire	Speed of recovery after fire	Improved as deer forage by fire	Remarks
Lechuguilla	Yes	Yes	None	Nil	No	Often main carrier of fire
Smooth sotol–old plants	Yes	Yes	None	Nil	No	Often "catches" lightning strikes
Young plants	No	No	None	Rapid	No	
Redberry juniper	Yes	No	Crown, stem, seldom	Slow	Yes	
Alligator juniper	No	No	Stem	Slow	Yes	Foliage often too high to burn
Oaks	No	No	Root	Moderate	Yes	Oak clumps do not carry fire
Hairy mountain mahogany		No	Crown	Moderate	Yes	Often rejuvenated by fire
Desert ceanothus	Yes?	No	Crown	Nil	No	Roots burn out
Catclaw mimosa	No?	No	Crown	Rapid	Yes	
Sacahuista	Yes	No	Crown	Variable	Yes	Sometimes killed
Skeleton goldeneye		No	Crown, root, stem	Rapid	Yes	
Silver dalea		No	Root and crown	Rapid	Yes	
Skunkbush	Yes?	No	Crown	Rapid	Yes	
Datil yucca	Yes	Yes	Root	Moderate	Yes	Deer seek new leaves
Grasses	Seldom	No	Crown	Rapid	Yes	Often main carrier of fire

maintain juniper regrowth below the height at which livestock handling becomes difficult. Total forage for livestock and wildlife increases where redberry juniper stands are burned.

Adams et al. (1982) found that in the tallgrass prairie of Oklahoma late winter burning (March) was more effective in reducing density of woody species than summer (July) burning and that herbaceous vegetation was less affected than woody plants. *Schizachyrium scoparium* (little bluestem) was dominant. Most woody species' density decreased with summer or late-winter burn. Decreases were found in poison ivy, roughleaf dogwood, black willow, green ash, winged elm, eastern cottonwood, eastern red cedar, black hickory, and post oak. Increases were found in smooth sumac and common persimmon. Mixed response was found in chickasaw plum and dwarf sumac.

Phillips (1987) indicated that wildfires once controlled eastern red cedar in Oklahoma, but by 1985 it had become a problem in 33 of 77 total counties. Prescribed burning controls eastern red cedar under 1.5 meters tall plus provides other benefits by removing all growth to improve grazing distribution and wildlife habitat. To kill trees that survived prescribed burns, Engle and Stritzke (1992) developed a propane torch technique. Igniting scorched trees after a prescribed burn in several positions killed 90% of the crown and two-thirds of the trees, regardless of tree size. Reburning was more effective on trees highly damaged after prescribed burning. Effectiveness of a single-point ignition declined with increasing tree size.

Engle and Stritzke (1995) concluded that understory eastern red cedar can be controlled successfully by burning leaf-litter firebeds in either late fall or winter after natural leaf fall from hardwood trees or in late summer, fall, or winter following a spring application of tebuthiuron for the control of overstory hardwoods.

3. Aspen

Gruell and Loope (1974) postulated that suckering of aspen and growth of palatable grasses, herbs, and shrubs following extensive fires, particularly on winter range, produced a forage supply sufficiently large to overcome biotic effects of ungulates, thereby allowing successful regeneration of aspen stands. Because of the advanced stage of plant succession, current production of aspen suckers and associated palatable forage is drastically reduced from former levels on elk winter range. Gruell and Loope (1974) concluded that the current decline of aspen stands is primarily due to virtual elimination of fire as an ecological agent in the twentieth century. Adopting fire management policies would reintroduce fire into the aspen–sagebrush habitat of Jackson Hole, Wyoming, and help maintain aspen communities.

Bartos and Mueggler (1979) also found that aspen suckers on high-intensity burns decreased the first postburn year and doubled the second. On moderateintensity burns aspen suckers tripled the first year, increased sevenfold the second year, and were still three times as numerous as before burning by the third year.

The effect of short-duration heavy grazing by cattle was evaluated 3 and 6 years after the burning and seeding of an aspen grove in Canada (Bailey et al., 1990). Replicated paddocks of June-grazed (early), August-grazed (late), and ungrazed treatments were established. Regardless of treatment, the density of all woody species was lower 6 years after burning than after 3 years. Early- or late-season grazing reduced the density of aspen and wild raspberry (*Rubus strigosus* Michx.) Late-season grazing promoted a greater density of unpalatable western snowberry (*Symphoricarpos occidentalis* Hook.). Grazing reduced the height of aspen, preventing the development of a forest canopy. Herbage production averaged 1,700 kg/ha, not differing between years 3 and 6, but the proportion of smooth brome (*Bromus inermis* Leyss.) increased, while orchard grass (*Dactylis glomerata* L.) declined. Burning of aspen forest in central Alberta followed by forage seeding and short-duration heavy grazing is an effective, economical range-improvement tool.

4. Chaparral—California

Early improvement of brushland for livestock production was expanded in the 1940s and 1950s, most commonly using fire (Fenner et al., 1955). Area ignition applied during sage-burning periods is a safe and effective method. Area ignition is the distribution of many individual fires over an area simultaneously or in quick succession. These individual fires are spaced so that they influence and support each other. This system is particularly suited to land clearing on many California brush ranges. It can also be combined with brush smashing in advance of burning to create concentrations of fuel accessibility. Area ignition spreads fire at a controlled rate and can be accomplished quickly (within a few hours). It is not well suited to areas in which dry grass is the principal surface fuel, but rather to brush and brush litter (chamise and mixed chaparral).

Conversely, Countryman et al. (1969) described a wildfire in which seven Los Angeles County firefighters and their foremen were overrun by a fire flareup and fatally burned. The Canyon Fire burned over 20,000 acres (8,900 ha) before it was finally controlled. The Canyon Fire started on August 23, 1968, near Canyon Inn. An analysis of the fire load index (FLI) was made for the period from August 21 through August 24. On August 23, a sharp rise in air temperature and a drop in relative humidity caused a large rise in the FLI. The chief chaparral fuels at the disaster site were sumac, scrub oak, chamise, and sagebrush, with a few sycamore and introduced shrubs and trees. The last fire in this area was in 1919. No fire had occurred for 70 years or more, and a heavy accumulation of litter and standing dead material was present. Because of the steep slope and strong convective wind currents, the flames were held close to the ground so firefighting crews were subjected to maximum temperatures with fire whirls. The increase in the speed of the local airflow may have resulted from the sea-breeze front reaching the fire area or caused by turbulence by a low-level air tanker flying through the area (or both) just before fire flareup.

Countryman (1974) indicated that the best prospect for alleviation of conflagration fires in southern California is modification of the vegetation to reduce fuel energy output. Creation of the fuel-type mosaic would require coordinated area-by-area planning and a variety of techniques.

Countryman (1983) described the physical characteristics of five northern California brush species—greenleaf, manzanita, snowbrush, chinkapen, mountain whitethorn, and bitter cherry. Ash content ranged from 3% for chinkapen to 8.5% for bitter cherry in foliage. Average ash content in woody material was 1.6%. The ash content of dead material was 1.4%. Leached plants with a low percentage of ash and phosphorus burn more readily than unleached plants of high ash and phosphorus content. Fuel density (weight per unit volume) affects ignition. Fuels with low density can be ignited in a shorter time or with less heat than high-density fuels. Density of foliage varied widely among species, from 0.05 g/cm^3 for bitter cherry to 0.88 g/cm^3 for greenleaf manzanita. Living wood was similar for all species (0.5 to 0.7 g/cm^3). Deadwood density was highly variable, but averaged about 90% of that of living fuel. Solvent extractives, surface-to-volume ratios, heating values, fuel loading by size classes of materials, relative amounts of dead and living fuels, vertical distribution of fuel elements, and the amount of litter fuel were provided.

Vallentine (1989) indicated that controlled burning was the most widely used range-improvement tool for California chaparral. Complete conversion of chaparral to herbaceous range has generally required burning, grass seeding, and herbicidal control of brush sprouts and seedlings. Late fall burning results in less sprouting of brush than spring burning. Rainfall of 43 cm or more is recommended on land being converted to grass.

According to Wright and Bailey (1982), chaparral is a major plant association in California and a small part of south-central Oregon composed almost entirely of shrubs 0.6 to 3.0 meters tall covering about 4 million ha. Chaparral communities are bounded by forests above and grasslands below. Chamise (***Adenostema fasciculatum***) is the most abundant and widespread of all chaparral shrubs in California, and the genus manzanita (***Arclostaphylos*** spp.) is the second most abundant group of shrubs, with both sprouting and nonsprouting species. Other common shrubs include Christmas berry, wedgeleaf ceanothus, desert ceanothus, scrub oak, and western mountain mahogany. Only the ceanothus species are nonsprouters. In addition to chamise, on south-facing slopes plants such as California sagebrush, black sage, white sage, California buckwheat, and deerweed occur.

5. Arizona Chaparral

Low-value shrubs have been invading southern Arizona grassland ranges for many years (Humphrey and Everson, 1951). These woody plants generally produce much less forage than the grasses they replace. In a study by Humphrey and Everson (1951), burning before summer rainfall killed most of the burroweed (*Haplopapus tenuisectus*) and snakeweed (*Gutierrezia lucida*). Jumping cholla (*Opuntia fulgida*), and cane cholla (*O. spinosior* and pricklypear catus *O. engelmannii*) had 61, 32, and 44% mortality. Lehmann lovegrass (*Eragrostis lehmanniana*) stand was reduced about 33%, but after 1 year the grass had recovered.

Reynolds and Bohning (1956) burned two grass-shrub areas in the semidesert grassland type in southern Arizona on the Santa Rita Experimental Range near Tucson. Burroweed was reduced 90% from a single burn, while cholla was reduced 50% and prickly pear by about 25%. Velvet mesquite, the most undesirable shrub, was reduced only 9%. Of the mesquite trees killed, all had basal stem diameters <15 cm. All trees <5 cm were affected, but 60% of them resprouted. Black grama was seriously damaged by burning and did not recover during the study period, but the perennial three awns and other grasses recovered by the second to fourth growing season.

Pond and Cable (1960) evaluated the effects of fire on several chaparral species in central Arizona. Shrub live oak (*Q. turbinella*) was difficult to kill by burning; skunkbush sumac (*Rhus trilobata*) could be killed by burning but it took about one burn each year for 4 or 5 years to completely kill the plants. Wrights's silktassel (*Garrya wrightii*) was killed by four annual burns or two burns spaced 2 years apart; burning less frequently did not kill sprouts. Two annual burns or two burns spread 2 years apart completely killed hollyleaf buckthorn (*Rhamnus crocea*). One burn killed old desert ceanothus plants, pointleaf manzanita (*Arctostaphylos pungen*), and larchleaf goldenweed (*Aplopappus laricifolius*). Pond and Cable (1960) concluded that the possibilities of reducing less desirable shrubs by broadcast burning were remote. The species more easily killed are of the most value to livestock and deer.

Chaparrel crown copy and total shrub weights were still increasing six growing seasons after a wildfire on Mingus Mountain (Pase and Pond, 1964). Pointleaf and pringle manzanita and desert ceanothus plants were greatly reduced by fire, but their seedlings were numerous after 5 years. Herbaceous species production was small except where shrub canopy was controlled by herbicide.

Approximately 25% of each of three small watersheds was treated in strips of 15, 30, and 60 meters wide in each of 4 years (Pase and Lindenmuth, 1971). A fourth watershed was not treated. Treatment consisted of late-summer spraying with a commercial mixture of 2,4-D and 2,4,5-T, and prescribed fire in late September or October. Shrub crown cover was reduced an average of 94%. Most shrubs resprouted and quickly reestablished control over the site. Seedlings of desert ceanothus and manzanita were abundant. Herbaceous cover, low before the treatment, increased greatly in the early postfire years. Grasses were uncommon both before and after treatment. Litter mass averaged 14 tons per ha before treatment; 66% remained after the prescribed fire. Results show good but very