FUELBREAKS AND OTHER FUEL MODIFICATION FOR WILDLAND FIRE CONTROL

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Agriculture Handbook No. 499
April 1977

U.S. Department of Agriculture

Forest Service

Library of Congress Catalog Number 76-600063

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Green, Lisle R.
1977. Fuelbreaks and other fuel modification for wildland fire control. U.S. Dep. Agric., Agric. Handb. 499, 79, p., illus.

In Mediterranean climates, the shrubby plant cover and the coniferous forest above it are vulnerable to frequent large fires. The fuelbreak, a strip of land in a strategic area—such as a ridgetop—where fuel modification and often type conversion can be accomplished, is an approach to fire suppression being widely applied in the Western United States, particularly California. The fuelbreak concept and fuel modification practices have been developed extensively since the 1950's. Fuelbreak system planning is integral to land-use and fire control planning. Fuel modification practices include clearing of original cover by hand or machine; prescribed burning, with preparation of brush by crushing or desiccation with herbicides; control of brush regrowth with herbicides, as sprays or pellets; and establishment of new ground covers, immediately after clearing. Perennial grasses are preferred as new cover where possible; low-growing woody vegetation is also used.

KEYWORDS: fire management, chaparral, fuel modification, fuelbreaks, prescribed burning, herbicides, type conversion.

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402-Price $1.50
Stock Number 001-000-03587-8
Class Number A 1.76:499

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PREFACE

This handbook summarizes the work of the fuelbreak program over the 17 years of its existence. The Los Angeles County Department of Forester and Fire Warden, the California Division of Forestry, and the Forest Service, U.S. Department of Agriculture, organized the program for research and demonstration, and have supported the program generously, Other Federal, State, and county agencies including the U.S. Department of Agriculture's Agricultural Research Service and Soil Conservation Service, the California Agricultural Extension Service, and the San Diego County Department of Agriculture have participated in various phases of the work. Several cooperative studies were made with the University of California, and a lesser number with other educational institutions. Most of the handbook is based on inhouse and cooperative studies, but results of other pertinent research are quoted. Cost data presented have been updated to 1974, using Consumer Price Index data.

INTRODUCTION

A variety of fuel modification practices are applied in overall management of the vegetation on wildlands. These practices include the cultural treatments necessary in producing and using timber, forage, water, or other resource products, as well as any treatments aimed solely at modifying fuel characteristics of brushland or understory vegetation on timberland. The aim of fuel modification treatments may be a limited or temporary effect—for example, a single cleanup of hazardous debris or a periodic reduction of fuel volume by burning. The treatment objective may also be a permanent change to a new vegetation cover.

In wildland fire control, most fuel modification has been done to establish fuelbreaks—the permanent conversion of vegetation on strategically located areas for fire control which occupy a relatively small part of the total wildland acreage. Other fuel modification practices may be employed on part or all of the land in between the fuelbreaks. In California, where the wildland fire problem is acute, experience has shown that conversion of the vegetation on wide fuelbreak areas to a relatively stable plant cover can greatly reduce maintenance efforts.

The term "fuelbreak" has become widely used since it was first coined in 1957, but it has not always had the same meaning. Essentially it denotes a permanent break, or change, in the fuels themselves: expanses of heavy or highly flammable fuel are broken up at strategic locations by wide blocks, or strips, of lighter fuel which are maintained indefinitely. By extension, the term is also applied to a broadly conceived management practice in which establishment of fuelbreaks is a primary operation. In California, a broad research and administrative effort—the "Fuel-Break Program"—which was aimed at developing techniques and implementing wide-scale establishment of fuelbreaks, has been maintained over a period of more than 17 years.

Three firefighting agencies—the California Division of Forestry, the Los Angeles County Fire Department, and the Forest Service, U.S. Department of Agriculture—started fuelbreak establishment on an interagency project basis in southern California during 1957. A first objective was to adapt the brush-to-grass conversion techniques being used in northern California to the problem of controlling brush regrowth on many wide breaks being cut through brushfields in the southern counties.

As a part of this effort, a research group in the Pacific Southwest Forest and Range Experiment Station was organized to improve and evaluate fuel modification practices. The broad assignment was "Develop, test, and evaluate methods for breaking up or otherwise modifying expanses of brush or other wildland fuels to facilitate fire control. Evaluate potential changes in fire intensity, fire spread, and control difficulty resulting from modification in fuels. Integrate into fire control planning the practical fuel reduction practices that result from this research. Integrate the research with watershed, timber, wildlife, and other resource values."

The specific research subjects were selection of critical areas; mechanical and chemical brush control techniques; plant materials and establishment techniques for revegetation; fuel characteristics and fire resistance of native and exotic plants; and fuel modification through grazing, prescribed burning, and other means (U.S. Department of Agriculture, Forest Service 1957).

The work of the "Fuel-Break Program," though carried out in California, has useful implications for areas of similar climate, terrain, and vegetation throughout the world. This publication summarizes the experience gained since the Program began, some of which has been reported in the literature, and includes results of other workers where relevant to fuel modification.

In the reports summarized here, terminology varies, and the following definitions are offered for clarification:

Fireline—a narrow line, 2 to 10 feet wide, from which all vegetation is removed down to mineral soil, by sterilization of the soil, by yearly maintenance, or by clearing just ahead of firing out the line. The fireline may be a roadway or simply a strip cleared by hand or machine, strictly for fire control purposes. Often it is a line within a wider break, such as a roadway within a fuelbreak.

Firebreak—specifically, a fireline wider than 10 feet, frequently 20 to 30 feet wide and sometimes wider (fig. 1), prepared each year ahead of the time it may be needed for use in controlling a fire (U.S. Department of Agriculture, Forest Service—California Region, n.d.).

The term firebreak is sometimes applied to relatively narrow, strategically placed breaks recleared each year, or periodically, for possible use in fire control. These lines are too narrow to fit the definition of fuelbreak below. Hundreds of miles of such firebreaks were prepared during the 1930's.

Firelane—an access line, prepared either ahead of a fire or in advance of the fire season, to provide a foot or machine route at a strategic location. The line may later be cleared to serve as a fireline, or widened into a firebreak, during suppression of a fire. Many miles of such access line were prepared as part of preplanning activities during the 1950's and earlier.

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Figure 1.–A fuelbreak (top), usually 200 to 300 feet wide, is vegetated in contrast to a firebreak (bottom), which is generally much narrower, and from which vegetation is cleared each year, or as needed.

Fire control line—the mineral soil line actually used in firing out an area during fire suppression activities.

Fuelbreak—a strategically located wide block, or strip, on which a cover of dense, heavy, or flammable vegetation has been permanently changed to one of lower fuel volume or reduced flammability (fig. 1), as an aid to fire control. (In practice, almost any wide break cleared of all or part of the existing vegetation for fire control purposes is called a fuelbreak, but the term is misapplied unless long-term maintenance of a new vegetation cover on the cleared area is specifically planned.)

Fuelbreak system—usually, a system of relatively large areas of naturally open vegetation, or converted vegetation cover, all interconnected by fuelbreaks to form strategic locations for control of fires.

Fuel modification practice—the broad approach to fuel management on a large acreage of wildland. It has three basic elements: (1) cleanup of fuel hazards on limited areas, usually hazards resulting from man's activities, such as construction operations or logging, or from catastrophes such as major storms; (2) periodic fuel reduction on all, or most, of the large acreage, by burning or by other treatments; and (3) permanent fuel reduction (type conversion) on limited areas of strategic importance—on interconnected fuelbreaks and around areas of high value—which make up only a portion of the total acreage, perhaps about 5 to 10 percent. Combinations of these elements are often made: for example, fuelbreaks may be established in preparation for gradually expanded periodic fuel reduction treatment over the intervening acreage.

Fuel modification treatment—an individual treatment or specific technique used to modify fuels as part of the broad practice or approach to fuel management. Treatments such as bulldozing, burning by specific prescription, and reseeding are examples.

FUELS AND WILDFIRE—THE CALIFORNIA PROBLEM

A large part of the information in this handbook is drawn from experience in fire control in California. In that area, fuel modification is a response to particularly hazardous conditions produced by a combination of climate, fire weather, and terrain. Where new vegetation patterns can be developed, fires can be more readily controlled. The possible reduction in the high costs of suppressing conflagrations and damage from such fires gives fuel modification efforts priority in management of California wildlands.

Climate, Fire Weather, and Fuels

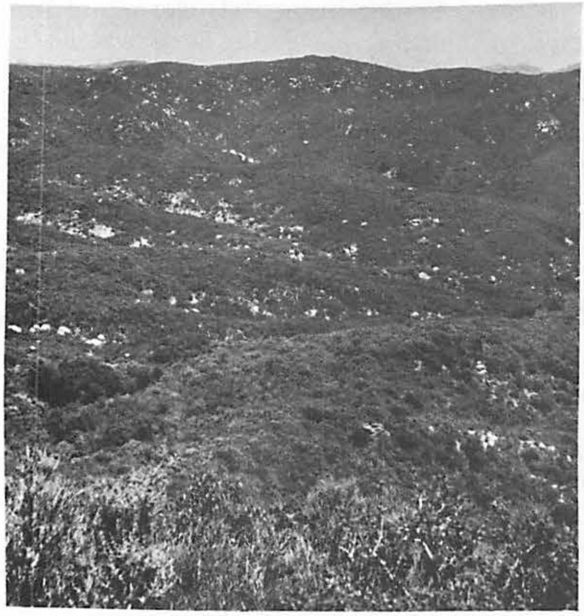
The winter precipitation and long, dry summer typical of climates in California favor growth of woody vegetation that becomes hazardous fuel during long periods of the year. The months May through September typically are almost lacking in precipitation. In low-rainfall areas of California, the precipitation may be concentrated during a few storms from December to March. The wet season extends over a much longer period in the coniferous forests of northern California. The variations in length of wet season and in total precipitation from south to north and from valley to mountain slopes are reflected by differences in density, height, and weight of woody fuel produced.

The shrubby plant covers found on millions of acres in the foothills and mountains of California could scarcely be designed to burn more readily than they do (fig. 2). Chamise (*Adenostoma* spp.), the most abundant shrub in much of the chaparral, is a prime example. Countryman and Philpot (1970) in southern California found that an average of 61 percent of the dry weight of chamise plants was in the leaves and stems less than half an inch in diameter. Other common shrubs, such as manzanita (*Arctostaphylos* spp.) and scrub oak (*Quercus dumosa* Nutt.), have one-third to half their weight in components of this small size. These potential fuels have tremendous surface-to-volume ratio spaced perfectly for air circulation.

The coniferous forests typically have dense stands of brush or small coniferous reproduction, singly or mixed, in the understory—and this fuel frequently is stair-stepped into the foliage of taller trees (fig. 3). Again, the arrangement of small stems, twigs, and needles draped over the understory vegetation is ideal to support intense fires.

A layer of duff and litter accumulates on the ground surface as chaparral matures and becomes decadent. On typical sites, the layer may equal one-fourth to half the weight of the aerial plant parts. Under scrub oak on good sites, the layer may be several inches deep. At the other extreme, under chamise on a poor growing site, the sparse duff layer of less than one-half ton per acre is likely to be discontinuous, with much bare soil showing between shrubs.

In addition to the accumulations of dead litter on the ground, shrubby vegetation in California con-



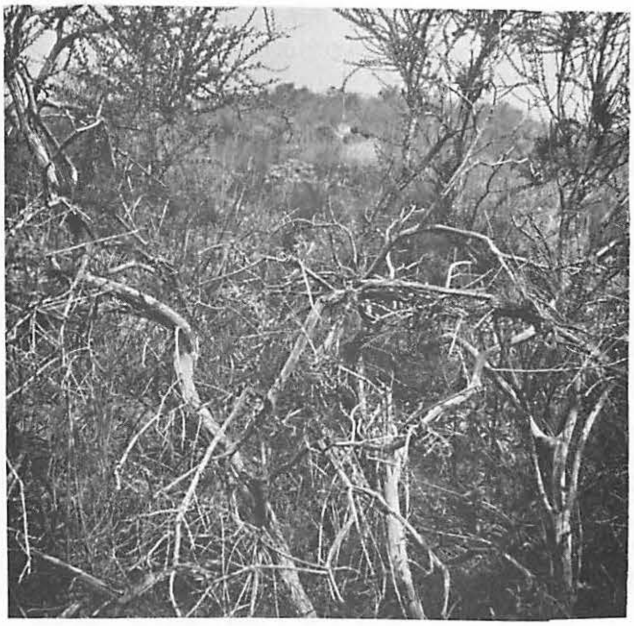


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Figure 2.—Extensive brushfields (left) dominated by evergreen shrubs such as chamise, manzanita, ceanothus, and scrub oak are known as "chaparral." Mature chaparral (right) has an umbrella of green twigs and leaves covering a thicket of dead branchlets which are easily ignited during wildfire. These dead branches are typically 25 percent or more of the aerial fuel.

tains a high proportion of dead upright stems after the stands approach maturity. Moisture stress is extreme during the long dry season when daily maximum temperatures commonly average between 90° and 100° F, and frequently are above 105° F. Relative humidity is low during this season, except near the coast, with minimums down to 5 percent. In areas of low total precipitation, the supply of dead stems greatly increases during consecutive years of below-average rainfall (Buck 1951).

The amount of dead fuels may equal 5 to 50 percent of the total upright vegetation but the proportion of green and dead plant parts depends on such things as age of the stand, the brush species, and the site conditions. After a chaparral stand has been reduced to year zero in its development by fire or mechanical clearing, it normally develops minimal dead aerial fuel until at least year 15. After about 20 years some plants of short-lived species have matured and died; and gradually the effects of periodic drought produce increasing proportions of dead fuel on all species. Dead fuels develop more quickly on dry sites where shrubs such as chamise and coastal sage species tend to lose leaves during summer, and twigs die (fig. 4). Dead branches may become as abundant as live branches. Scrub oak and other species of mixed chaparral commonly grow on somewhat moister sites and produce a smaller proportion of dead aerial fuel.

The fuel situations on California wildlands are made more hazardous by flammable materials which are present in coniferous fuels and some shrubs, such as chamise. These waxes, resins, terpenes, and other materials, which are highly flammable and frequently volatile, contribute greatly to intensity of wildfires.

The yearly weather pattern typical of California climates has produced fuel situations favorable for wildfire burning during a long period each year. However, at any given location at any given time during the wildfire season, the current weather more than anything else determines severity of the fire problem. The most critical situations develop in fall months during periods of warm, dry foehn winds, called "Santa Anas" in southern California and "Monos" farther north. Intensities of these dry winds at ground level vary from a few miles per hour to as great as 100 miles; sustained speeds of 30 to 50 miles are not uncommon. Large fires (fig. 5) which develop during such weather spread rapidly and commonly are not extinguished until the winds subside, when cooling temperatures and rising humidity ease the job of the firefighter.

The cumulative effects of past and present weather determine moisture contents of both the dead and the living fuel components (Schroeder and Buck 1970). The moisture in living fuels drops gradually during the dry season, from early summer

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Figure 3.—The ponderosa pine forest frequently has an overstory of "leave" trees, but an understory of brush and conifer seedlings and saplings that must be removed during fuelbreak construction.

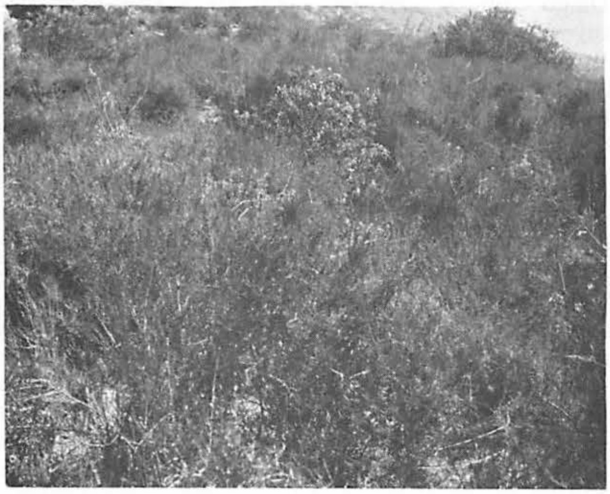

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Figure 4.—The coastal sage type is dominated by sage (*Salvia* spp.), California sagebrush (*Artemisia californica* Less.), California buckwheat (*Eriogonum fasciculatum* Benth.), and chamise. It burns intensely because of flammable species, fine stems, and heavier accumulations of dead stems than are common in chaparral.

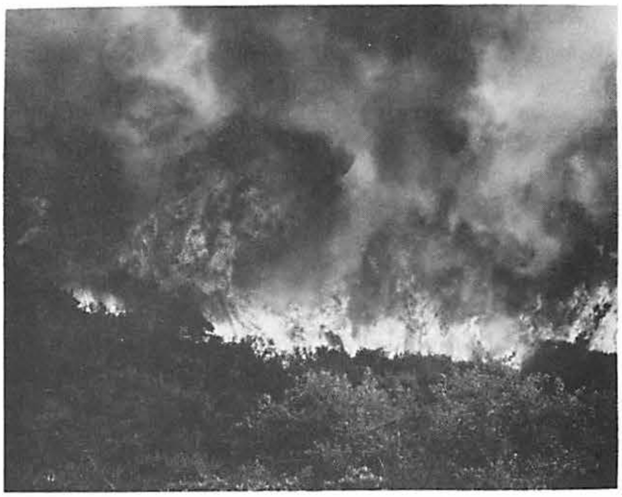

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Figure 5.—Conflagrations develop during periods of high winds and temperatures, and low relative humidities. Volatile products, distilled from the chaparral, burn above and beyond the burning brush.

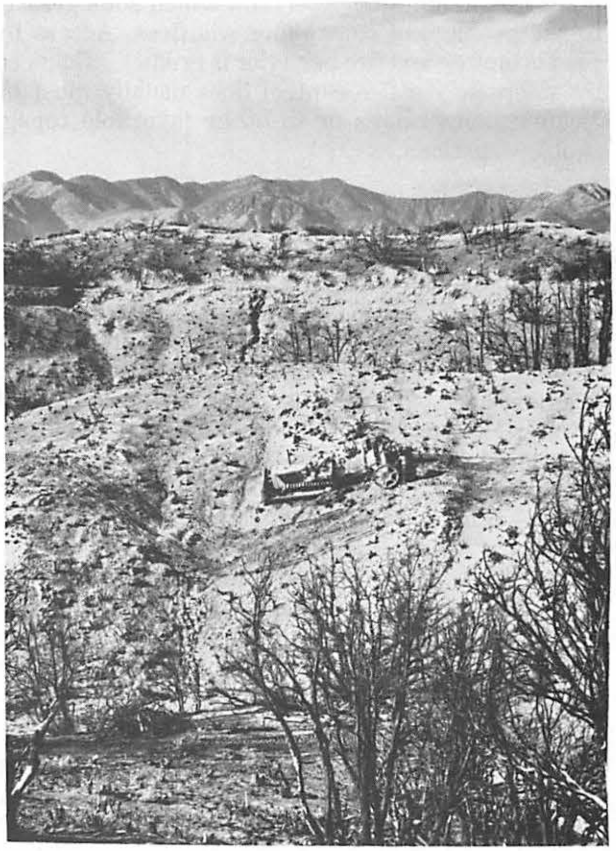

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Figure 6.—The rugged rangeland drill is shown here on a relatively gentle slope on the San Dimas Experimental Forest, in the San Gabriel mountains of southern California. The drill is usable on only 14 percent of the 17,000-acre Forest, however.

until fall. For new twigs of chamise, the typical decline is from about 160 down to 65 percent moisture content on a dry weight base; and for fine twigs at least 1 year old the decline is from 95 down to 60 percent. During one drought year, 1960–61, which followed several dry years, a mixture of new and old leaves and twigs of chamise contained only 74 percent moisture in May and was down to 45 percent from mid-July into October (Pirsko and Green 1967). The lowest moisture content recorded for living fuels was during Santa Ana winds on October 31, 1961, when fine twigs showed 25.7 percent for chamise and 35.8 percent for scrub oak (Pirsko and Green 1967).

Ease of ignition, rate of fire spread, and intensity of burning increase as the fuel moisture drops. Experience suggests that moisture in fine living fuels in mature brushfields becomes critical at around 60 to 70 percent moisture content. At times when moisture is below this level, fire spreads rapidly and control becomes difficult if the burning index is high or extreme. Under a combination of severe fire weather, adequate ground litter and dead aerial fuel, and low moisture content of both dead and living vegetation, most of the biomass becomes fuel which will support a fire.

Wildfire Control

The hazardous wildland fuels of California occur mainly on mountainous terrain, which adds greatly to the problem of controlling wildfires. Access by road is limited and fire behavior is greatly influenced by steep slopes; fire control lines usually must be located along ridges or in other favorable topographic situations.

The most difficult problems during critical fire weather occur on the extremely steep terrain typically found in many parts of the Coastal Ranges and in southern California. For example, a sample of 46 watersheds of 20 to 234 acres each in the Los Angeles River drainage showed an average slope gradient of 68 percent, a surface acreage 20 percent greater than map area, and channel gradients averaging 44 percent (Sinclair 1954). On the San Dimas Experimental Forest, a 17,000-acre area in the San Gabriel Range, 44 percent of the land has a slope gradient of 70 percent, or greater. Some 86 percent of the area has a slope gradient greater than 55 percent, the maximum gradient for efficient tractor operation (Bentley 1961). In a fuels study on this area, slope gradient at plot locations varied from 0 to 92 percent with an average of 62 percent (fig. 6).

The explosive fuel and weather situations in steep terrain in California have necessitated development of large, highly organized firefighting forces. Even with these difficult situations, the highly efficient suppression forces stop 95 percent of the many California wildland fires before they exceed 10 acres in size; and less than 2 percent of the fires reach conflagration proportions. Yet, between July 1960 and August 1974, 64 fires in California burned over 10,000 acres each.[1] These big fires were rather evenly divided between northern and southern California. Of the 64, 29 occurred north of an east-west line through San Francisco, and 31 south of a line between San Luis Obispo and Bakersfield.

Of the several fires started October 29 or 30, 1967, in southern California, the Paseo Grande fire in Riverside and Orange Counties burned nearly 50,000 acres and consumed 57 dwellings, the Bailiff fire in Riverside County burned over 20,000 acres and 16 structures, the Ramona-Woodson fires in San Diego County burned 33,000 acres and 25 structures, and other fires burned to about 15,000 acres. In June 1968, the Liebre fire in Los Angeles claimed one life as it burned over 50,000 acres of watershed; in August, the 20,000-acre Canyon fire took nine lives; and in September, three fires burned 17,500 acres of chaparral and destroyed 13 homes; three firefighters were lost. Two large fires burned in southern California in 1969. During 1970—the worst fire season of all—nine conflagrations raged out of control between September 25 and October 3.

The large fires represent extremely high costs, in addition to the normal high costs required to equip, maintain, and operate the large firefighting forces. Suppression costs on large fires have recently averaged more than $100 per acre.[2] But the expense only begins when a large watershed fire is declared controlled. The 22,000-acre Johnstone fire, of July 1960, is a good example. Immediate costs included the

[1] Compiled from California Division of Forestry and Forest Service, U.S. Department of Agriculture, fire reports, on file Forest Fire Laboratory, Pacific Southwest Forest and Range Experiment Station, Riverside.

[2] Compiled from National Forest fire reports covering large fires during 1970–74.

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Figure 7.—The bill for a wildfire may not be total until after some winter rains. Here, erosion debris is being removed from a flood control reservoir.

value of 30 homes and cabins which were burned. During the next 2 years, costs reported by the Angeles National Forest, Los Angeles County Road Department, and Flood Control District (Rice 1963) were:

Extra road maintenance	$164,000
Aerial seeding	40,000
Reinforcing structures	54,000
Debris basin clean-out	659,000
	$917,000

Continuing costs included later flood damage to homes, a school, and Forest Service facilities; plus considerably more road repair and reservoir clean-out (fig. 7). And 11 years after the fire, in 1971, an estimated 1 million cubic yards of debris were removed from Dalton reservoir at a cost of nearly $1 per cubic yard. Another large reservoir also has had debris removed twice since the Johnstone fire.

The staggering costs of the large fires illustrate an acute need for reducing their occurrence, through improved fuel management and all other aids to control of fires on California wildlands.

THE FUELBREAK CONCEPT

The "fuelbreak approach" to fire control combines the old concept of clearing strategically located areas before fire breaks out, and the newer concept of removing, controlling, and sometimes replacing undesirable vegetation as part of a long-term plan. Firefighters in California long ago observed that on large brushland fires, final fire control lines were commonly located within natural openings in dense brush. These openings, occupied by less dense vegetation such as open woodland, were naturally made use of when they occurred at suitable strategic locations. Present-day attempts to establish new vegetation cover on wide strips or blocks of land, now called fuelbreaks, are a logical outcome of fire control experience.

Early Firebreak Construction

The need for breaking up vast expanses of dense woody fuels by openings of some kind, even if these were only narrow strips, was recognized early in the history of organized fire control in the State. In 1886, a recommendation to the State Board of Forestry called for blocking out the forest with strips of "waste" land wide enough to prevent fire from crossing. In 1904, the Diamond Match Company and the McCloud cooperative study recognized a need for firebreaks, and some, 200 to 400 feet wide, were constructed (Clar 1959). These firebreaks were areas cleared of brush, but still occupied by trees and ground vegetation.

In 1905, 12 miles of firebreak were constructed around the Big Basin Redwood Park in Santa Cruz County. In 1907, new legislation allowed the State to expend money for the purpose of cutting firebreaks to protect timber, provided the Forest Service supplied matching funds. By 1912, $50,000 of State funds had been spent on firebreak construction in the San Bernardino mountains, and other sums were spent for the same purpose elsewhere in southern California (Clar 1959).

S. B. Show, District Forester, proposed in 1929 the construction of a firebreak at the interface of the chaparral and pine forest along the east side of the Sacramento-San Joaquin Valley, the entire length of the Sierra Nevada (Clar 1969). Neither Federal nor State financing was then available, but about 4 years later Emergency Conservation Work programs, particularly the Civilian Conservation Corps (CCC), made construction possible. During the fall of 1933, California Division of Forestry and Forest Service personnel delineated the route of what came to be known as the "Ponderosa Way and Trucktrail." Construction started at the Pit River northeast of Redding, and terminated about 650 miles southeastward at the northern border of Kern County, near Kernville. The cleared strip was generally 150 to 200 feet in width. Trees were left where possible, but brush was removed. A roadway was constructed wherever one did not exist near the firebreak.

The CCC was active in firebreak construction throughout its existence, and hundreds of miles of fireline, on which vegetation was removed to the soil, were cleared throughout the State.

A notable firebreak construction job—now called the "International" fuelbreak—along the border with Mexico, was started by the California Division of Forestry in 1952. The strip was cleared to a width of 300 feet, and over several years, as resources allowed, to a length of 41 miles (White and Green 1967). In another firebreak project of District 6, California Division of Forestry, a 60,000-acre brushland was broken up by firebreaks, access roads, roadside hazard reduction, and supporting fire control facilities (Blanford 1962).

Transition—The Type Conversion Approach

The transition from firebreak construction to permanent modification of vegetation on a broad scale—the fuelbreak approach—came about as part of pre-attack planning in the early 1950's. New techniques of vegetation control showed promise for overcoming the maintenance problems that had limited past use of wide firebreaks.[3] The type-conversion techniques used for rangeland improvement in northern California had been fairly well developed and appeared to be economically feasible for establishing and maintaining new plant covers on large acreage.

The problem of controlling regrowth of woody vegetation was most apparent on the thousands of acres of brushland cleared during the 1930's. When manpower became limited after termination of the CCC program, brush recaptured a major part of the firebreaks. The Ponderosa Way was a prime example; by 1950 the woody vegetation had regrown to the extent that the original location of the wide break was hardly discernible in many places. But exceptions occurred in spots where shrubby regrowth had been virtually eliminated—apparently by deer browsing, possibly aided by fire—and a fairly stable grass cover had developed. All observations showed definitely that intensive treatments would be required to hold down brush regrowth and develop stable new covers. Wildlife browsing alone could not be depended on for adequate brush control, although use of cleared areas by wildlife could be important in maintaining stability.

Type conversion as an element of fuelbreak establishment is based on sound ecological principles (Bentley and others 1966). On large cleared areas, some kind of continuous ground cover is needed for esthetic reasons, to protect the soil, and to serve other useful purposes. After brush removal the initial ground cover tends to be a mixture of herbaceous plants (natural or sown species, or both) with regenerating brush plants (seedlings and sprouts). This gradually develops into a woody plant cover, the period of time depending on the site, the woody vegetation type, thoroughness of the initial brush removal, and intensity of follow-up brush control. Under all conditions, however, the woody plants eventually dominate and produce undesirable fuel conditions—unless control efforts virtually eliminate the woody plants at some stage of vegetation cover development.

Successful type conversion requires eradication of excess brush seedlings and sprouts during the first few years after initial brush removal, before they compete heavily with the new plant cover. Some old trees or shrubs, and perhaps some regenerating sprouts or seedlings, are often left as scattered plants or in clumps or larger thickets for landscaping, for wildlife habitat, or for other reasons. In California practice, the new ground cover has commonly been dominated by annual grasses, but it may include perennial grasses and other low-growing plants, or, on timbered fuelbreaks, it may be perennial grass or bearmat *(Chamaebatia foliolosa* Benth.*)*. Once fully established in adequate density on productive sites, the ground cover uses moisture from the upper soil and competes heavily with any new brush or tree seedlings during the long dry season. A vigorous new ground cover can thus slow reinvasion of woody plants and lengthen the allowable time between maintenance treatments.

Effective methods of establishing and maintaining vigorous new ground covers and reducing the need for brush control have not been determined for all of the many different wildland sites. On some chaparral areas successfully converted to perennial grassland 10 to 20 years ago, the reestablishment of brush has been minimal, and little, if any, maintenance effort has been needed.

On some soils rated as not well suited for perennial grass production, the vigor of herbaceous cover has declined greatly during the first 15 years after conversion to grass; brush seedlings may establish themselves at a much faster rate in the future and periodic maintenance probably will be needed. On soils well suited for producing fair to good grass

[3] The account given here of the early history of fuelbreak activities is based on information supplied by Jay R. Bentley, of Pacific Southwest Forest and Range Experiment Station (now retired), who had charge of the initial Fuel-Break Research Program.

crops, the grass cover has persisted for many years after removal of woodland and some chaparral types; apparently little maintenance effort will be needed in the future, perhaps only occasional burning. On some sites of low productivity, especially under low average precipitation in southern California, where yearly rainfall is erratic, stable herbaceous covers may never develop; dense stands of brush seedlings may become established in years of heavy rainfall and require fairly frequent maintenance effort.

Even though type conversion may be less successful on some sites, and benefits from forage production or other tangible returns may be low or somewhat temporary, the basic attempt at early elimination of excess brush regrowth can still pay off in reduced maintenance effort on fuelbreaks. Continued study of past and future conversion jobs is needed, with possible eventual modification of both concepts and techniques.

Type-conversion attempts during the 1950's were not designed merely to reduce maintenance requirements on fuelbreak areas. New vegetation covers and patterns also serve productive purposes under a multiple-use plan of resource management—habitat improvement, increased forage or timber, improved access for recreationists, more esthetically pleasing landscape, and other benefits. The kinds of covers to be established and the benefits that result are of course determined primarily by site conditions.

The "Fuel-Break Program"

The "Fuel-Break Research and Demonstration Program," organized in 1957, was designed to expand construction of wide breaks in southern California, to gradually incorporate type conversion as a means of reducing maintenance problems, and to develop and improve techniques of vegetation management on fuelbreaks. This program was later extended to all California wildlands.

Availability of labor provided by correctional facilities of the State and some counties stimulated fuelbreak construction during the 1950's and early 1960's. After 1965, less inmate labor was available and less money was provided through regular appropriations. Consequently, the rate of new fuelbreak construction declined markedly.

The California Division of Forestry reported a total of 1,353 miles of fuelbreak being maintained in December 1970 (personal communication 1971). Of this, 39 percent was over 300 feet wide, 41 percent was 200 to 300 feet, and 20 percent 100 to 200 feet. Fuelbreaks on National Forest land are more difficult to estimate. About 1,400 miles have been cleared (personal communication, Oliver L. Holmes, 1972), but for lack of funding, much of this mileage has not been fully established and maintained. Also, a considerable amount of it was constructed cooperatively by the California Division of Forestry and is included in the 1,353 miles reported as maintained. We may assume, however, that about 500 miles of maintained fuelbreak on National Forest lands were not included. About one-third of this is less than 200 feet wide.

It is reasonable to say, then, that in 1972 there were some 1,850 miles of fuelbreak wider than 100 feet in California. The fuelbreaks are distributed fairly widely throughout the State. Those constructed by the California Division of Forestry are in the North Coast district (13 percent), Sierra Cascades (32 percent), South Sierra (28 percent), Central Coast (11 percent), and southern California (16 percent).

The primary reason for expansion of fuelbreak establishment during the 1950's and 1960's was the feasibility of the fuelbreak approach to wildland fuel management. The manipulation of vegetation on any large scale was not acceptable then as a management practice if aimed mainly at fire control, and even now, questions remain on its advisability. Fuelbreaks, however, mean drastic change of only limited portions of the land to be protected. The areas of greatest strategic importance to fire control may be only 5, 10, or 15 percent of the total. Devoting this low proportion of the land to reducing the hazard from wildfire losses can logically be justified under any objective of land management.

Similarly, broad-scale fuel modification was limited by the patterns of land ownership and human occupation on California wildlands. Fuelbreaks affecting relatively small areas could be established under almost any pattern, even though permits for rights-of-way caused legal problems and cooperative assistance of landowners was often lacking.

Fiscal and legal restrictions also limited the total amount of fuel modification effort. Neither public nor private funding has ever been adequate for effective fuel manipulation on even the small fraction of the wildland acreage in California desired for fuelbreaks. It seemed reasonable, however, to concentrate much of the fuel management effort and money into areas where greatest success could be assured.

Evaluation

Fuelbreaks are intended to provide locations suitably prepared for use in attacking wildfires which escape initial control efforts. They have also aided initial control of fires starting near them. The wide breaks covered with low-volume fuels are expected to assure successful holding of firelines in all situations where backfiring can possibly contain a fire.

What Fuelbreaks Can Do

Fuelbreaks can provide safe access for quick manning of fire control lines (fig. 8). Low-volume fuels, especially flammable grass, can be fired out quickly to widen a fireline under conditions where backfiring would be impossible in heavy fuels having high heat output.

The light ground fuels on fuelbreaks are particularly useful when rapid burning out of a long line is needed. Such action is typically required to contain a large brush fire at times when moisture content of fine fuels may be up—as in the evening and morning—but when woody fuels are dry and burn readily, with high heat output. Commonly, rapid firing and holding of long lines will contain a fire at the end of the first burning period. But the slow firing required on newly prepared, narrow firelines will not succeed. With slow firing, lines cannot be closed before weather conditions become critical the next day, and the fire is lost across the hoped-for lines of control.

Fuelbreaks at strategic locations are intended to divide large expanses of woody fuels into small blocks. This allows quick manning of lines and relative ease of backfiring, or control of fire as it reaches the fuelbreak, so that the spread of wildfires is limited. Aerial attack can be used effectively along with ground crews. With adequate fuelbreak systems, lateral spread of large fires can be contained. The burned-over acreage can be greatly reduced, even though the heads of raging fires under extreme burning conditions may cross over one or more fuelbreaks.

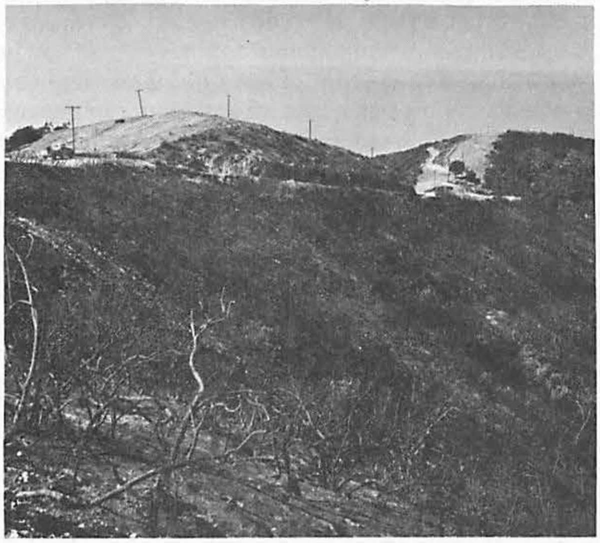

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Figure 8.–This fuelbreak on a strategically located ridge above Glendora, on the Angeles National Forest, allowed quick manning and backfiring to stop the fire which ran uphill to the fuelbreak.

Adequate fuelbreak systems can aid firefighters when more than one large fire is burning out of control in a given area. The separate fires can be contained more quickly along the fuelbreaks, where lines can be fired rapidly, well removed from burning heavy fuels.

What Fuelbreaks Cannot Do

A strong criticism of the fuelbreak approach to fire control is that the headlong rush of a large fire can carry it across a wide break—manned or not—under extreme conditions. Firebrands carried downwind can cause spot fires which spread quickly at distances of a quarter of a mile, or farther, ahead of the main fire front. Attempts at backfiring from a single wide fuelbreak seldom, if ever, are effective in stopping a fire of this kind—at a time when help is most needed. Unmanned fuelbreaks seldom, if ever, stop the large, fast-moving fires. Some slow-moving fires, however, have stopped on reaching a fuelbreak ahead of firemen. The presence of the fuelbreak eased control efforts and reduced acreage burned.

A disadvantage of grassy fuelbreaks on steeply sloping lateral ridges is the possibility that a "fuse effect" may spread fire rapidly uphill towards the main ridgeline, increasing the size and intensity of a fire burning out of control. The possibility can be minimized by effective aerial attack on fires in grass covers.

An obvious limitation of fuelbreak systems is the heavy, hazardous fuel which normally remains on much of the intervening land—that is, on most of the total wildland acreage. Fires in such heavy fuels are extremely difficult to control. Even if improvements in firefighting techniques provide quicker, more massive attack during windy weather, in smoky atmosphere, and during darkness, control of fires in heavy fuels will continue to be difficult and perhaps impossible under severe conditions.

Experience With Fuelbreaks

Fuelbreaks have been useful in suppression of some of the many California fires extinguished before they burned 10 acres. More frequently, fuelbreaks are not involved in control efforts until a fire becomes larger. Then their usefulness depends on their locations, on how they are used, and on wind and fuel conditions.

Although no formal survey has been attempted, many instances of the use of fuelbreaks in fire control have been described. The narrative report section of the Fire Report covering the Romero fire of October 6–12, 1971, near Santa Barbara, Calif., contains this account:

> If there was one successful feature in this fire it was the East Camino Cielo fuelbreak which served as final control line for approximately twelve miles. Without this fuelbreak, which enabled men, equipment, and air tankers to control that part of the fireline, it is certain that a large portion of the valuable Santa Ynez River Watershed, which supplies water to the entire Santa Barbara South Coast, would have been destroyed. In addition we believe that the fire would have rapidly spread across the Murietta Divide into the Matilija drainage, which had not burned since 1932.

Fuelbreaks were used to advantage at times during the period of September 25 to October 3, 1970, when 140 fires blackened 430,000 acres in southern California. The 10-year-old Pine Valley fuelbreak, even though poorly maintained, was backfired as winds of 40 miles per hour hurled flames toward the community (fig. 9). This was credited by the Cleveland National Forest Fire Control Officer with saving 30 homes (personal communication, Myron K. Lee). No attempt was made to use three other fuelbreaks—Morena, Corte Madera, and Japatul—to stop fire spread within the area burned by the Laguna fire in San Diego County. As the fire approached these fuelbreaks, it was being speeded by spot fires one-fourth to one-half mile ahead of the fire front. However, access along fuelbreaks allowed tanker crew protection of 30 or more homes in the community of Corte Madera, with the loss of only one; similar success was attained along the Japatul fuelbreak. Tanker crews did not go to the aid of the community of Hidden Glen because there was no fuelbreak, and the road ended. There, 11 of 14 homes burned.

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Figure 9.–Sprouting brush was never eliminated from this fuelbreak between the community of Pine Valley, San Diego County, and surrounding brushfields. It had been without maintenance for 10 years, yet was credited with the assist firefighters needed to save scores of homes during the Laguna fire of 1970.

Fuelbreaks assisted markedly in controlling the Tecate fire, which started September 25, 1970. Grass on 5 miles of the International fuelbreak was backfired as the fire burned more or less parallel to the fuelbreak. The Barrett fuelbreak, fired by California Division of Forestry crews, formed the southern terminus of the fire.

The Middle Peak fuelbreak was constructed along a road in brush and timber along the northwest corner of the Cuyamaca Rancho State Park. The fire backed into the fuelbreak against the wind and was stopped by backfiring after earlier attempts to keep it away from the Park had failed. The 100- to 150-foot clearing along the road would not have been adequate against fire pushed toward the break, but under the existing conditions, it was credited with a big assist in keeping fire out of one of the few remaining islands of conifers in southern California.

During the late afternoon of October 1, 1971, the Foothill fuelbreak—lying between the towns of Upland and Cucamonga, Calif.—slowed the Meyers fire and was credited with a "save" of scores of homes. Grass on the fuelbreak was fired as the wildfire approached, at times only a few hundred feet away. Winds aloft were 40 to 50 miles per hour, but surface winds were much less during the firing, and the fuelbreak line held.

Many other instances of the value of fuelbreaks could be cited. The International fuelbreak near the border with Mexico has frequently been useful.[4] The Julian-Sunrise fuelbreak, also in San Diego County, has been used to stop six fires during several years under "severe" weather and fuel conditions, although the nearby Pala fuelbreak was jumped by fire three times in 5 years.[5]

Narrative reports covering Class E fires (300+ acres) on the National Forests give other indications of fuelbreak use. On the Angeles National Forest, for example, fuelbreaks were used effectively on 11 fires between 1962 and 1968.

[4] Baldwin, Lewis. 1970. Personal conversation. Calif. Div. For., Div. VI. He was fire boss on the Tecate fire.

[5] Donohue, Emmitt. 1970. Personal conversation. Calif. Div. For.; Julian, Calif.

James A. Jay compiled a brief report relating to fuelbreak encounters on 11 fires in California, after talking with personnel on the forests concerned.[6] Estimates of additional land area that would have burned without the aid of fuelbreaks on five of the fires totaled 10,290 acres. Suppression costs for these saved acres were estimated to be $538,000 or $52 per acre.

Excellent use was made of a fuelbreak in the timber forest type on July 11, 1968, when wildfire spotted across the north fork of the Tuolumne River and spread rapidly up the slope toward the Miller Ridge fuelbreak, which had been constructed 6 years earlier. The change in cover type from chaparral to woodland grass, plus the change in topography, enabled crews to backfire and hold the line against repeated runs out of the canyon. There is no doubt that without the fuelbreak there would have been no stopping the fire short of the next ridge complex. An additional 1,000 acres of mixed commercial timber and brush would have burned, with additional suppression costs estimated at $60,000.[7] As an interesting sidelight, the line boss, when asked about use of the fuelbreak, replied, "There was no fuelbreak. We stopped the fire in the opening on top of Miller Ridge," thereby attesting to an excellent fuelbreak design.

Finally, in an undated report, "Soboba Fire Statistics," The San Bernardino National Forest stated that "this section broke the fire front and provided an avenue for ground attack. Controlling the fire here was the key to saving the North Fork Drainage." The Soboba fire burned 17,683 acres near Idyllwild, Calif., August 27–28, 1974.

Thus, fuelbreaks have been used many times to stop wildfire under severe fire weather conditions but generally not under the most extreme conditions. During extreme fire weather, fuelbreaks have been useful for reducing the lateral spread of fires, occasionally for stopping head fires during lulls in the wind, and for making possible the protection of isolated communities.

The economic value of fuelbreaks is difficult to estimate, partly because in the short history of fuelbreak use, little experience in control of wildfires on areas adequately protected by fuelbreaks has been analyzed from this point of view. Until recently only two studies in depth of California fuelbreak economics had been made (Davis 1965; Murphy 1965), and both relied heavily on assumptions about dollar values and fire behavior. Davis' study covered northern California brush and woodland; Murphy's covered Central Sierra mixed conifer forest. They arrived at quite different conclusions. In 1973 a third economic study was completed by the Stanford Research Institute.[8] It included modeling as part of the analysis of wildland fire protection.

Davis used decision gaming to acquire "data." A series of 32 hypothetical fire-fuelbreak encounters were devised and presented to 10 men experienced in wildland fire problems. Each man was asked to predict the probability of success in controlling the fire at the fuelbreak. Results by consensus were as follows: Assuming extreme burning conditions, with fire spotting to one-half mile and the fuelbreak 350 feet wide, the forces had only about 20 percent chance of stopping fire at the fuelbreak. With a 1,000-foot-wide fuelbreak, there was 21 to 50 percent chance of stopping such fires. With fire spotting to only one-fourth mile, there was a medium (21 to 50 percent) chance of stopping the fire at a 350-foot-wide fuelbreak, and a greater than 50 percent chance if a fuelbreak was 1,000 feet wide.

Davis estimated that a complete system of fuelbreaks occupying 2 to 10 percent of the land area would reduce burned acreage by only about 5 percent, and that a considerably enlarged suppression force, taken together with the fuelbreak system, would achieve only a 10 to 15 percent reduction. The marginal cost of saving an acre from being burned was estimated to be at least $700. Davis gave as a reason for the failure of greater reduction in burned acreage, "the fundamental technological inability of direct suppression forces to cope with conflagration-type fires when they are making a major run." He concluded that within the limits of assumptions used in his study, neither extensive fuelbreak systems nor substantial additions to conventional fire suppression forces appear economically justified, and that increases in funds for wildfire protection should be used to construct fuelbreaks around high-value areas rather than for extensive fuelbreak systems or for more direct suppression forces.

Davis made no allowance in his analysis for use of fuelbreaks under less than extreme burning conditions, nor did he consider their usefulness in restricting fire spread along the flanks during periods when forward spread was rapid.

Murphy's study area encompassed 40,000 acres of the Stanislaus National Forest that had an active multiple-use program, high-hazard fuels, and a history of conflagrations. Cost records were kept during construction of about 50 miles of fuelbreak. A dollars-per-acre damage potential to timber,

[6] Jay, James A. November 6, 1967. A look at fuel-breaks. Report on file, U.S. Dep. Agric. For. Serv., Washington, D.C.

[7] Murphy, Eugene E. Personal communication, 1968. Stanislaus National Forest, Sonora, Calif.

[8] Harrison, J. Michael, D. Warner North, and Carl-Axel S. Staël von Holstein. 1973. Decision analysis of wildland fire protection: a pilot study. Stanford Res. Inst. Proj. 1555. 196 p., illus. Report prepared for the FIRESCOPE Program, U.S. Dep. Agric., For. Serv., on file at For. Fire Lab., Pac. Southwest For. and Range Exp. Stn., Riverside, Calif.

watershed, recreation, grazing and improvements was estimated to be $1,235 for timber and $305 for brush. Murphy also used decision gaming, by which experienced firemen estimated how many times in a hundred varying densities of fuelbreaks could have been used to hold fires that had occurred during a 50-year period. His analysis indicated that conflagration control by use of fuelbreaks, with a specialized hard-hitting fire control organization, was economic and justified at a level based on control of fires in timber at about 8 acres, and at 3 acres in brush.

The Stanford Research Institute decision analysis team studied the economics of fire protection strategies in southern California. Data from watersheds that had burned off in the Great Matilija fire of 1932, above Ojai, Calif., were important in their deliberations and modeling. In such areas chaparral is the principal fuel, and watershed damage and postfire damage to urban areas are principal results from fires.

As part of the overall study, and to answer the question, "Is it economically advisable in the representative area to engage in an extensive program of fuel modification?" three levels of fuelbreak activity were considered. These were: (1) no fuel modification, (2) a system of conventional fuelbreaks, and (3) a system of expanded fuelbreaks, up to a mile in width, created and maintained mostly with prescribed fire.

The principal conclusion from the Stanford group is that a program of fuel modification is economically justified in their representative area. Less obvious is which of the two systems is best, although alternative 3 is slightly preferable to 2. The general tendency of all fuel modification was to reduce the number of large fires, and to reduce wildfire damage and suppression costs. Costs of establishment and maintenance, however, particularly of the expanded fuelbreak system, were almost sufficient to offset the benefits.

The findings of the Stanford group justify earlier expectations. Observations of fire control efforts on several large fires in southern California before the days of fuelbreaks convinced experienced firefighters that adequate fuelbreak systems surely would have made it possible to confine the fires within specific canyons and cut acreage burned and suppression costs by 50 percent, or more, on the different fires (personal communication, Jay R. Bentley, 1957–60). Later flood damages also would have been similarly reduced. The widespread interest in prefire fuel modification seems to insure that fuelbreaks will continue to be part of the battle against conflagrations.

Fuelbreak establishment can be a feasible first approach to wildland fuel management. But establishment of conventional fuelbreaks has never been considered as the ultimate answer, nor as the only fuel modification practice to be employed. For example, a fuelbreak system to aid in control of wildfires can serve equally well as established control lines for prescribed burning on intervening areas. Periodic burning of adjacent areas, for habitat improvement or fuel reduction, can gradually widen the fuelbreaks and greatly increase their effectiveness for control of wildfires.

Reduction of fuel volume on all of the wildland has been proposed as the logical way to make modern firefighting techniques more effective. Even if such action could be taken, however, it would not stop all fires. Hazardous fuels will always build up on California wildlands. Well-prepared control lines at strategic locations always will have a place in aiding control of wildland fires.

Planning Fuelbreak Establishment

Planning a fuelbreak system is an essential part of pre-attack fire control activities on any large land area. Once the basic fire control strategy and needs have been decided, however, fuelbreak planning should become integral to the total process of land-use planning. That is, a natural fire control unit, once defined, can become a part of the total pattern of resource development—combining with such elements as timber plantations and wildlife habitats.[9] Fuelbreak systems planned in this manner can aid in protection of the new resource values, fit into an esthetically pleasing vegetation pattern, and make more efficient use of resource development funds. In other words, the most effective planning is accomplished by fire control specialists working with the other resource management specialists (Murphy, Green, and Bentley 1967).

Basic Pre-Attack Planning

The principles and guidelines for pre-attack planning—spelled out in the R-5 Handbook (U.S. Department of Agriculture Forest Service—California Region 1959)—were based on experience gained in planning fire protection on southern California forests. Coordinated efforts of all fire protection agencies are meshed in the pre-attack plan. All of a management unit is studied on aerial photos, reinforced by reference to resource inventories and

[9] Bentley, Jay R. 1970. Designing fire safety into pine plantations. Paper presented to Cal-Nevada For. Fire Counc., Redding, Calif., on file at For. Fire Lab., Riverside.

planning maps, and by driving and walking over the unit. The pre-attack plan ultimately prepared shows location of access lanes, firebreaks, fuelbreaks, and other facilities which may be needed by fire suppression forces, along with detailed information on fuels and other physical features of the land unit.

The intensities of fuelbreak systems, the number and location of fuelbreaks, and the size of units of natural fuels are determined by fire control objectives (Fuel-Break Executive Committee 1963; Green and Schimke 1971). Entire systems are planned, even though construction of some breaks may not be completed for years, and priorities for construction are indicated.

An outstanding example of fuelbreak system planning and construction is the project "Management Designs for Conflagration Control," also referred to as the Duckwall Administrative Study (Bower 1963). This plan covered a 40,000-acre area of fine timberland on Duckwall Mountain, Stanislaus National Forest, which has been the site of many fires.

The first step in the Duckwall program was a complete pre-attack survey and then a plan for the area. A team of fire specialists, who had been oriented in the various management plans for the unit, did the planning. They drove, or walked, all major ridges and canyons, locating fuelbreaks, firebreaks, fire camps, heliport locations, tractor unloading points, water source locations, and other fire needs (Murphy 1963). Planned management projects—in range, wildlife, recreation, timber, and watershed along with the forest road and trail programs, were reviewed to see how they could contribute to the objective of breaking the area into 2,500-acre blocks for conflagration control.

During the construction phase of the Duckwall program, fuelbreaks were constructed as part of timber harvest, with some special clearing on the fuelbreak site. Brush areas on fuelbreak locations were converted to perennial grass or to timber, depending on the site. Other hazard reduction and recreation development work added to the fuelbreak area. Finally, additional clearing or thinning of vegetation on steep slopes or other sites where management activities had not produced a fuelbreak was needed to connect the various segments into a continuous system.

Fuelbreak Locations

Systems of interlinked fuelbreaks encompassing large areas are much preferred over isolated single breaks or segments. The fuelbreak locations may be classed as primary or secondary, with respect to construction priorities.

Most fuelbreaks are planned for locations where need is greatest for protecting urban development or valuable natural resources. The first to be built are usually those most needed to help prevent fires from sweeping for miles across country (Fuel-Break Executive Committee 1963). These primary breaks are commonly located on prominent ridges that separate major drainages. The ridgetop usually is accessible, and it breaks the forward momentum of a fire, thus facilitating control at this point. Primary fuelbreaks may also be at the base of mountains, in wide canyon bottoms, or elsewhere (fig. 10).

Secondary fuelbreaks are needed to break down large areas of fuels, to safeguard access to forests or brushfields, and to insure human safety and investment in special situations. Clearing along fire control roads makes them more usable for travel during fires, and allows them to serve as fire control lines under certain conditions. Fuelbreaks down spur ridges within primary fuelbreak systems break the areas of natural fuels into smaller blocks. Fuelbreaks around or within residential areas, organization camps, groves of trees, or other areas of special value can be fitted into the over-all fuelbreak system, and also into the landscaping of the developed areas.

An example of location planning in an intensive system is the plan proposed for the San Dimas Experimental Forest in the San Gabriel Mountains near Glendora, Calif. (Bentley and White 1961). On this area of extremely steep terrain and flammable fuels, the land-use objective was complete protection of the brushy watershed cover. A site survey (Bentley 1961) showed where fuelbreaks could be located with minimum disturbance of cover on extremely steep slopes.

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Figure 10.—Although fire control needs usually dictate location of fuelbreaks on ridgetops, the base of mountains or elsewhere may also be a desirable location.

Primary fuelbreaks were first laid out to represent the minimum system considered essential to control of large fires. These primary breaks were along the ridges surrounding the two major drainages. Primary or "first priority" fuelbreaks were also laid out to break one of the major drainages into three large areas. Secondary fuelbreak locations were planned on ridges within the major subdrainages to break the area into small units, so that fires might be confined in less than 1,000 acres. Fuelbreaks were also located along truck trails, roads in major canyon bottoms, wherever dwellings were situated, and around some plantation sites.

Fuelbreak Widths

Fuelbreak widths are determined by terrain, fuels, and expected weather conditions, and by economics. Recommended minimum widths are based on experience, reinforced by experimental and theoretical data on the distances at which radiated heat from an advancing fire will ignite vegetation, or produce skin burns on firefighters.

Tests have shown that skin burns requiring medical treatment can be expected whenever radiation exceeds 0.3 calories per square centimeter per second. Approximations have been made of the distances to which this amount of radiation would extend from the flame front under different burning conditions and fuels (Fuel-Break Executive Committee 1963; Green and Schimke 1971). Assuming "worst" conditions—fire burning up 70 percent slope in heavy brush fuel, with low humidity, and heavy winds blowing the flames 50 feet horizontally into the fuelbreak—132 feet must separate men on the control line from the flame front to prevent skin burns. Given a safety margin of 68 feet, 200 feet is the suggested minimum safe distance from fire front to control line.

Under actual burning conditions, firefighters could retreat to the edge of a 200-foot-wide fuelbreak temporarily while fuel at the other edge was consumed, and until radiation lessened. If a sharp ridge marked the center of a fuelbreak, protection from radiation would be afforded by crouching in the lee of the ridgetop, and somewhat less than 200 feet would be needed. Because of eddying along the ridgetop, however, a fuelbreak of such minimum width should be manned with caution.

Considerations such as these, plus experience in the field, are the basis for setting 200 feet as the minimum width for fuelbreaks in southern California. A minimum of 300 feet is often recommended for primary fuelbreaks. Breaks on flat ridges and saddles are frequently widened to provide an additional margin of safety, as well as turnouts and safety zones for men and equipment.

Suggested fuelbreak widths in the yellow pine forest of the Sierra Nevada Mountains are similar. Along a knife-edge ridge which drops away on 50 percent slopes, a width of 3 chains (200 feet) along the slope, or about 180 feet horizontal, is recommended. Where terrain is near level and fuels are dense to the edge of the fuelbreak, 5 chains, or 330 feet, is recommended (Green and Schimke 1971).

Minimum fuelbreak widths, as specified for safety of personnel attempting to control an oncoming fire under severe burning conditions, allow for relatively rapid backfiring from a fire control line under less hazardous conditions. Heat radiated from burning heavy fuel at one edge of the wide fuelbreak is not intense enough to preheat and dry heavy fuel on the other side of the break, and burning embers from one side of the break do not shower down across the break. Thus, the problems commonly encountered in firing out narrow firebreaks are avoided.

In general, the wider the break, the easier and safer the job of holding fire on it. Practical considerations limit the width of most fuelbreaks, however. It is seldom practical to construct a fuelbreak wide enough to intercept all burning embers under extreme conditions, for example. Budget limitations have commonly restricted fuelbreak widths to the minimum acceptable for fire control, or less.

Other Planning Considerations

Legal problems, fiscal limitations, and policy in expenditure of available funds have all combined to keep fuelbreaks near, or below, minimum desired widths. More important, these factors led to establishment of too many miles of straight-sided breaks. Often, the fuelbreaks have the jarring effect of artificial supersize firebreaks rather than natural changes in the vegetation cover. The original concept of fuelbreak establishment envisioned conversion to useful vegetation types on interconnected areas of irregular shape fitted to the terrain and changes in site conditions. Fortunately, more stress is now being put on this concept as fuelbreak planning is being tied more closely to total land-use planning, and esthetic values are being given much more consideration.

The legal problems have centered around contracting for rights-of-way on private lands and the fiscal necessity to use governmental funds strictly for fire control needs rather than improvement of private property values. Landowners frequently object to any encumbrances that might affect future sale or development; thus, obtaining rights-of-way agreements becomes difficult and time consuming. The simplest solution has been to make agreements cover a strip of specified width to be cleared along a fixed route.

The probable impact of the fuelbreak on an area—just what a fuelbreak is and what it looks like—has been hard to explain to property owners, and to the general populace interested in proposed developments on public lands. The California Division of Forestry[10] has found stressing the "landscaping" aspects of fuelbreak construction to be effective. Before a fuelbreak was built in mixed conifer along Highway 20, demonstration plots showing four levels of fuelbreak clearing were prepared. Landowners taken to the cleared plots, in almost every instance, chose the "heavy cut" as being most esthetically pleasing and desirable for their property. Variations in widths of rights-of-way for fuelbreaks, within legal restrictions for use of funds, might possibly come from a similar attempt at selling the landscaping feature.

With limited funds available, fuelbreak construction emphasis has been placed on building maximum length at minimum width, sometimes less than desired. When fuelbreaks were constructed with funds appropriated for fire control use, the common policy was to call for a specific width which was strictly adhered to, with minor exceptions in spots, such as saddles on major ridges where wider clearing was specified. More emphasis on landscaping features has changed this policy.

Combining fuelbreak planning with all other phases of land-use planning, along with combining resource development funds, overcomes the emphasis on a limited fire control approach to planning. And, as mentioned, much of the fuelbreak system can be incorporated into other resource management activities. Rangeland development has the built-in feature of hazard reduction through grazing, and wildlife habitat development can add browsing to help maintain the fuelbreak. Clearing to fuelbreak standards can be written into timber sale contracts and stand improvement operations; and planting, thinning, and pruning standards can be specified for portions of new plantations to be designated as fuelbreaks. All these developments that produce wildland fuelbreaks can add variations in vegetation patterns which improve recreational and scenic values. Fuelbreaks should enhance the natural scenery; in no case do they need to impair the landscape (Fuel-Break Executive Committee 1963).

Steps in Fuelbreak Construction and Maintenance

After plans for a fuelbreak system have been thoroughly integrated with fire control planning and over-all resource management, the actual construction and maintenance of a fuelbreak requires removal of excess woody vegetation, both dead and living, establishment of a new ground cover, control of regrowth of woody plants until a stable ground cover has been established, and periodic control of woody plants or reduction of herbaceous cover as needed to maintain the desired ground cover conditions.

If the new ground cover is to come from species naturally occurring on the site, the construction phase can be a somewhat gradual process spread over several years, particularly where prescribed burning is employed. But the brush removal and control treatments must be adequate to develop a stable ground cover situation within a reasonable time. If a new ground cover of introduced species is to be established, the initial brush removal must be accomplished within a year, and must include preparation of a suitable seedbed for the new species. Control of brush regrowth must start early to keep down competition from woody plants.

[10] Phillips, Clinton B. 1968. Personal conversation. Calif. Div. For., Sacramento.

In conversion of dense stands of shrubby plants, such as California chaparral, to a grass cover, the type conversion process is best considered as distinct steps, or operations: (1) removal of brush, including preparation of a seedbed if introduced species are to be sown; (2) establishment of a ground cover, including sowing or planting of introduced species; (3) control of brush regrowth to eliminate excess competition from woody plants; and (4) maintenance of the stable new cover (Bentley 1967). Each step must be taken at the right time to insure successful type conversion. All woody materials, except for shrubs or trees left as part of the new cover, are removed during the initial operation. A clean seedbed is prepared by broadcast burning of dense brush or by cultivating the soil surface with a bulldozer or disk. Grass seed is sown before the first fall rainy season after brush removal. Control of brush regrowth, which regenerates rapidly as sprouts or seedlings during the next spring and summer, is ordinarily started during the first year after grass sowing and is continued for a period, usually 2 to 4 years, until competition from woody plants is eliminated and a relatively stable plant cover has been developed. Periodic maintenance is applied if and when needed.

Construction and maintenance of almost any fuelbreak requires a combination of several different cultural treatments for removing and controlling woody vegetation and for establishing new covers. Some of these treatments also are used in over-all fuel modification on wildlands between the fuelbreaks. A very wide variety of treatment combinations must be employed because vegetation-fuel types and land management objectives differ, and for other reasons. Most treatments may be used in several stages of fuel modification, depending on circumstances, although specific techniques vary.

In succeeding sections, the various treatments are described and their benefits and drawbacks evaluated on the basis of experience reported. Information on costs is not complete, but wherever possible, cost estimates are included. (Unless otherwise noted, costs of work performed before 1974 have been adjusted to 1974 levels.)

FUEL MODIFICATION: REMOVAL OF VEGETATION

The first step in type conversion or less complete fuel modification is removal of unwanted vegetation, usually brush. Either hand or machine methods may be used, as well as burning by specific prescription.

Clearing by Hand or Machine

Land clearing by cutting or crushing brush, using hand or machine methods, has been practiced widely. Debris must be disposed of, and several ways have been found to do this, with varying impact on the environment.

Hand Methods

Land clearing by hand cutting or grubbing of individual shrubs and trees can be done with minimum disturbance of a site. Hand operations can be carried out on steep or rocky areas where clearing with bulldozers or other machinery is not feasible. Brush regrowth can be readily controlled by hand treatments near habitations, where other treatments, such as herbicides, are inadvisable or prohibited. Hand cutting is particularly appropriate for thinning woody vegetation if many trees or shrubs are to be left for landscaping or timber production.

Of course, the major deterrents to use of hand labor for brush removal and control have been the extreme cost, slow progress, and high manpower requirements. Effective combining of hand labor with machine operations, and with treatments such as prescribed broadcast burning, can reduce the manpower needs. But the slow progress and high costs probably will always prohibit use of hand clearing operations on extensive acreages of wildlands in California. A radical change might occur, however, if using the "waste" woody material as an energy source becomes feasible.

Initial brush removal.—Hundreds of acres of fuelbreak in California have been cleared by hand, generally by inmate labor available at low cost (fig. 11). The usual practice is to cut the plant stem above the root crown with a brush hook or axe, or a power saw. Choice of the most efficient tools depends on the size and shape of the plants. The severed topgrowth is piled or windrowed for burning; occasionally it is chipped.

Root crowns of some sprouting shrub species, such as chamise, commonly are grubbed out if they are easily removed. Large crowns, such as scrub oak, which may require up to one man-day per plant for grubbing, are seldom removed by hand. They are sometimes removed with a bulldozer; more often they are left for followup control of sprouts by hand

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Figure 11.—Many miles of fuelbreak have been hand cleared in California, using low-cost inmate labor. At commercial rates the cost of hand cutting, piling and burning, or hand cutting and chipping might approximate $1,500 per acre in heavy fuels.

cutting or by herbicide treatment. Grubbing ordinarily adds at least 50 percent to the manpower cost of cutting alone, and in oak chaparral it more than doubles the cutting cost. Grubbing of the smaller root crowns greatly reduces brush regrowth; it is worthwhile when the plan calls for followup by hand cutting, but is of little value when followup by broadcast herbicide treatment is called for.

Hand cutting by commercial labor is very expensive. At a cost of $32 per man-day, the initial brush removal job—cutting, piling, and burning—is about $450 per acre for light brush (10 to 15 tons/acre), about $850 for medium brush (20 to 25 tons/acre), and at least $1,200 for heavy mixed brush (30 to 40 or more tons/acre). Mileage, cost of small equipment, planning, and overhead add an estimated 40 percent (Roby and Green 1976). Such costs obviously have limited the use of commercial labor to small cleanup jobs or to areas where mechanical equipment cannot be used because of terrain, rock outcrop, or the presence of many "leave" trees that prohibit use of heavy machinery. Hand clearing has been done mainly with noncommercial labor.

The immense labor force required for clearing extensive acreage of brushland can be judged from the high requirement per acre. The initial removal effort requires approximately 15 man-days per acre for light brush, 25 man-days for medium brush, and 35 or more man-days for heavy brush. If power saws are not used in heavy brush, up to twice as much time is required. Other brush removal methods need to be combined with hand labor to lower the costs and to speed the job of clearing dense brushfields.

An example of hand clearing costs on fuelbreaks constructed through Sierra Nevada coniferous forest (Green and Schimke 1971) showed a direct cost (converted to 1974 prices) of $80 per acre for thinning of small coniferous trees, $42 per acre for pruning "leave" trees and shrubs, and $18 per acre for burning the debris. This type of clearing operation obviously can progress more rapidly and more cheaply than initial clearing of dense brush stands.

Burning hand-piled brush on the Stanislaus National Forest in the central Sierra Nevada was estimated by Green and Schimke (1971) to cost $18 per acre. An estimated cost between $20 and $50 per acre should cover burning piled brush on hand clearing operations in dense brush on any terrain.

Followup brush control.—The initial brush removal operation by hand cutting and grubbing seldom does a complete job of developing a stable vegetation cover. Brush regeneration proceeds much more slowly than it does after burning, but commonly faster than after bulldozing. Some small sprouting plants are missed during initial hand removal, and healthy brush seedlings appear on disturbed spots before a continuous herbaceous cover becomes well established. Density of regenerating cover depends on original density of sprouting shrub species, and on thoroughness of the initial removal operation. Intensive followup hand treatment, or other intensive followup control, is usually needed for at least 2 years after the initial hand clearing operation to bring the original brush stand under control—before the cleared area can be considered to be on a maintenance basis.

Such intensive followup soon after initial clearing was seldom accomplished during early-day construction of firebreaks. Instead, workers tried to keep an unstable vegetation cover under control by periodic maintenance. A brush stand still remained and soon covered the areas if maintenance was discontinued.

Hand operations, if persistent and sufficiently intense, can convert dense woody vegetation to open stands of lower fuel volume that are easily maintained. Often, the maintenance efforts can be aided by wildlife browsing or by burning. Hand cutting has an advantage over most other treatments in that plants to be left for wildlife habitat or for landscaping are more easily saved and protected.

Mechanical Methods

Land clearing by machine is much more efficient than hand cutting in both cost and rate of progress. Mechanical removal of dense woody vegetation has the major fault of heavy soil disturbance; it may leave unsightly scars, and its use is limited to slope gradients and soil conditions where erosion of bared soil is not a critical hazard. And, mechanized equipment cannot be used efficiently on many steep slopes nor on rocky ground. Mechanical brush removal can be used readily near habitations, provided soil erosion is not a hazard. Trees and shrubs can be left on the site if desired for landscaping; but heavy equipment cannot be used if the "leave" trees are too closely spaced.

Mechanical brush removal can have adverse environmental impact because of unsightly appearance of the land, increased erosion and sedimentation, and atmospheric pollution during burning of the debris. These faults can be largely overcome by wise selection of sites for mechanical clearing, exercise of proper care and skill during the clearing, and disposal of the debris by approved methods.

Costs for mechanical clearing of brushland are fairly high, even though much lower than for hand clearing. Again, an economic use for the "waste" woody material would make mechanical clearing more efficient.

To date, the bulldozer or disk has proved more efficient than other mechanical equipment for initial brush removal on California wildlands. Heavy equipment is greatly hampered by steep terrain; often the heavy machinery has not performed well

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Figure 12.—The bulldozer is more widely used for clearing brush than any other equipment. Soil disturbance can be excessive, however, if the work is not done carefully.

on slopes in excess of 10 to 15 percent gradient. Choppers with heavy blades mounted on large drums, widely used on flatland sites in other parts of the United States, have not performed well on moderate to steep terrain nor on rocky sites in California, for example. Heavy mowers similarly have had limited use in California.

The tractor with a *bulldozer* blade is the most widely useful mechanized equipment for clearing brush from California wildlands (fig. 12), and is the standard against which other clearing methods can be compared. The bulldozer works better than other equipment on irregular terrain and around rocks or trees, provided they are not too closely spaced. Trees and shrubs can be left as desired for the future vegetation cover. Soil disturbance can be minimized by setting the blade to sever shrub stems just above or at the soil surface.

Brush rakes, which have heavy teeth extending below and forward from the dozer blade, are useful for uprooting heavy root crowns and small tree stumps while moving a minimum amount of soil. But use of a brush rake over all of the ground results in complete disturbance of the soil surface.

Bulldozers work most efficiently on relatively rock-free, gentle or moderate slopes—up to 30 or 40 percent gradient. Efficiency drops off with increases in rock outcrop or slope gradient, and use of bulldozers is limited for brush clearing on slopes of more than 55 percent. The upper limit of slope gradient on which bulldozing is an acceptable practice depends on length of slope, soil stability, percent of area disturbed by the blade, and precipitation patterns. Site requirements for areas to be bulldozed should be determined locally.

Costs in 1974 for removing brush and pushing it into piles with a bulldozer, on gentle-to-moderate slopes, are $25 to $30 per acre in light brush, $30 to $50 in medium brush, and $45 to $65 in heavy brush. Costs go up rapidly with increase in slope gradient, and may be more than doubled on steep slopes. This increased price, along with erosion hazards, has held down the amount of bulldozer work in clearing of brush from steep lands. Costs for brush rake clearing tend to be somewhat greater than for bulldozer clearing, but the brush rake is even less well adapted for use in steep terrain.

Heavy offset *disks* pulled by a heavy tractor have been used for about 25 years to remove brush from California wildlands. The disk is most effective for removing semidense stands of light to medium brush, particularly chamise (fig. 13) and for dense stands of small brush plants. Most, or many, of the root crowns, except for the largest chamise, can be broken loose from their root systems by the large scalloped disks.

But the offset disk is not suited for removing heavy mixed chaparral and some kinds of medium brush having large root crowns just below the soil surface. Crowns of scrub oak and some manzanita species are not damaged seriously by disking. The disk blades often come out of the ground as they ride over the tough branches.

A single pass of the disk through light or medium chamise stands breaks many crowns loose from the roots, breaks up brittle stems, and leaves them partly buried and partly on the soil surface. Broadcast burning may be needed to complete removal of the woody material. Two passes—double disking—of most chamise stands will chop most of the stems into the soil, and leave the site almost devoid of woody material on the soil surface. Thus, double disking can be used for removing brush on some areas where burning of debris will cause problems.

Single disking of mature brush proceeds at a rate of about 0.8 acre to 2.0 acres per hour, depending on size and density of the brush and nature of the terrain; 1.0 acre per hour is typical for the first pass. Single disking of light brush on gentle terrain costs $25 to $30 per acre at 1974 prices, while double disking of medium brush on sloping terrain not exceeding 35 percent costs up to $50 per acre (Roby and Green 1976).

Slope gradient definitely limits use of disking for removal of brush. It is little used on areas having average slope gradient greater than about 30 percent where costs are $65 per acre, or more.

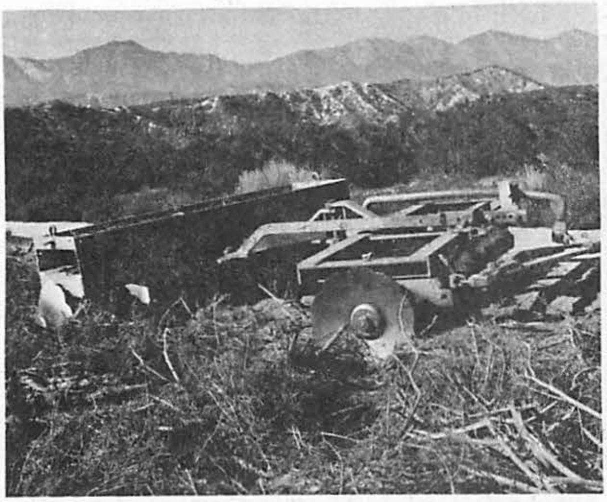 

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Figure 13.—The heavy brushland disk (left) is effective for light to medium brush, particularly chamise, frequently leaving the site suitable for drilling with the rangeland drill. Heavy chamise chaparral (right) is inadequately prepared for drilling after one pass; a second pass will uproot and mulch more of the brush.

Disposal of Debris

The problems of debris disposal are similar for hand clearing and for bulldozing operations, except that woody material accumulates much faster and usually is somewhat mixed with soil when removed with a dozer.

Burning.—Most slash and other debris from land clearing is burned during winter, or at other seasons of safe weather, in piles or windrows accumulated during the clearing operation. Sometimes, however, the piled material can be moved into a burner as clearing progresses or after the material has dried for a period of time. Occasionally it is burned in piles as it is being cut.

Burning within a portable, open-topped metal burner produces near complete combustion of green or dry woody material, with little production of either smoke or firebrands (Schimke and Dougherty 1967b). The material can be fed into the burner as it is being hand cut, or recently piled material can be mechanically loaded.

In one operation, a small crawler-type tractor having hydraulically operated front forks was used to load an open-top, skid mounted, metal "box" measuring 14 feet long by 8 feet wide. The burner was towed into a slash pile area, a fire was started, and green and dry slash was fed almost continuously into the burner (fig. 14). Disposal cost at 1974 prices was $1.20 per ton, dry weight. This cost compared with $1.35 per ton for piling and burning 15 tons per acre of slash under similar conditions, $2.85 per ton for burying slash, and $4.80 per ton for chipping.

Similar open burners built by Sierra Nevada timber operators were safely used during the morning hours from spring until early August. Enclosed burners are being tested for control of smoke pollution in areas where open burning is banned.

Burning of debris in piles or windrows is difficult after it has become water soaked and compacted during the winter. Compacted material, either wet or dry, is not readily ignited. The material burns slowly, especially when partially covered with soil, and the smoldering fire becomes hazardous if the weather changes.

Protective coatings have been tested to determine if dry slash in piles can be protected against wetting at reasonable cost, using asphalt or wax emulsions (Schimke and Murphy 1966). The coated slash piles burned well at times when only 40 percent of uncoated slash would burn, but cost of materials alone was $20 to $30 per acre. (The consumer price index rose approximately 33 percent, 1966–1974.) The authors suggest that alternatives be considered. In another test, coating of green slash with emulsions proved to be an unsatisfactory practice (Schimke and Dougherty 1967a).

Ignition aids, such as a petroleum gel in blivet or bulk form, have been widely tested for igniting slash and promoting burning. Blivets are easily placed, and bulk gel is easily applied with a hand gun. With these aids, partially wet slash piled by hand or with a dozer was readily ignited when untreated piles could not be ignited with a fusee (Schimke and Dougherty 1966a). In an earlier test, Murphy and Schimke (1965) found that an incendiary powder, which

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Figure 14.—In one slash-disposal operation, green or dry slash was burned in a portable slash burner as fast as a small tractor-loader could feed slash piles into it.

burned intensely for several minutes, did not ignite wet slash efficiently.

Wind machines frequently are suggested for increasing rate of wet slash combustion, and to reduce time and expense of burning. Although big blowers may be useful in burning large piles of heavy material, our tests with a small fan showed it to be inefficient. The 18-inch fan, which produced a 40-mile-per-hour air stream, increased combustion within the stream, but the fan had to be moved several times to complete burning of a single pile of slash. Burning with a diesel oil flame thrower was more efficient than using the wind machine (Schimke 1963).

Chipping.—Chipping offers several advantages for disposing of woody debris. It may be done as clearing progresses throughout the year; in fact, slash is frequently most readily chipped when it is still green. Chipping overcomes the problems of winter burning of piled brush and the possibility of fire escaping at other times of year. The absence of smoke prevents pollution problems. Chipping also can enhance esthetic values, because disposal of slash reduces possibility of fire damage to "leave" trees and the associated risk that fire-damaged pines will become "bug trees"—centers of Ips beetle infestations.

A major disadvantage of chipping is the cost, unless commercial use can be made of the chips. Equally important is the limitation of small portable chippers in handling stems larger than a few inches in diameter. Large chippers being developed to handle logs up to 20 inches diameter will be expensive and difficult to move, and will require large power sources. They will probably be useful for specialized situations rather than for general slash disposal.

Good estimates on costs of chipping operations come from a fuelbreak clearing operation on the Stanislaus National Forest (Schimke 1965) where a heavy stand of conifer saplings and poles, about 8,000 per acre, was thinned, piled, and chipped. Costs updated to 1974 were thinning, about $5.80 per ton; piling, $5.35 to $7.40 per ton; and chipping, $3.00 for piled air-dried slash, and $5.25 per ton for green slash. Chipping rate per hour was 4.8 tons of air-dry slash and 3.5 tons of green slash. Ease of handling of dry material was credited with the rate and cost differential. Green weight removed was 33.6 tons per acre, and the chipping cost about $175 per acre.

Casamajor and Wilson (1957) estimated that cost of slash chipping averaged $2.25 (1974 prices) per thousand board feet of lumber, where 2,000 to 15,000 board feet per acre were cut—costs of $4.50 to $34 per acre. In contrast, Cook (1966) estimated an average slash chipping cost of $27 per thousand feet when only 2,500 feet per acre were cut. Details given in both sources were insufficient to explain the wide differences in costs, but indications were that not all of the slash was chipped in the operations reported by Casamajor and Wilson.

Burying.—Burying of both brush debris and conifer slash has been tested in a limited way (fig. 15) in an attempt to overcome the problems and hazards of burning, and to eliminate air pollution.

On one study on the Stanislaus National Forest, brush and logging slash was buried following logging of 40,000 board feet of merchantable timber (Schimke and Dougherty 1966b). About 18 tons of

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Figure 15.—A pit about 6 feet deep can be excavated on suitable sites, slash pushed into it, compressed, and covered at costs less than those for chipping but more than for tractor clearing and pile burning.

brush, 6 tons of cull logs, and 17 tons of logging slash, a total of 41 tons per acre, were buried at a cost of $2.40 per ton, or $98 per acre at 1974 prices. In comparison, chipping of only the portion under 4 inches in diameter would have cost $160 to $220 per acre. Tractor clearing and burning of debris would have cost about $85 per acre.

McKell and associates (1966) cleared and buried about 15 tons of brush per acre from 7 acres near the campus of the University of California at Los Angeles. Tractor costs at 1974 prices would be about $94 per acre, or $6.25 per ton of brush buried.

In a study on 53 acres of Deschutes National Forest, an estimated 40 tons of ponderosa pine (*Pinus ponderosa* Laws.) thinnings and partial-cut logging slash were buried for about $63 per acre, or about $1.60 per ton (personal communication, Franklin R. Ward). In a second area, similar material on 17 acres was gathered and buried for $66 per acre.

Like chipping, burying of woody debris can keep a cleared area neat and clean, ready for its fire control job, without the problems associated with burning. Earth mounded over the buried slash piles will prevent development of depressions in the ground after the woody material has decomposed. Silviculturists may be concerned about root diseases arising from buried woody material, but we have no reports of problems arising on fuelbreak areas.

Prescribed Burning

The term "prescribed burning" designates the planned use of fire for killing and removing vegetation in place over all, or nearly all, of the land surface within a predetermined area. This spread of fire over an area is also called broadcast burning, as distinguished from burning of piled debris. Prescriptions, or guidelines, for safe and effective burning are determined by the purpose of the burning and by the specific conditions of fuel, terrain, and weather observed or expected on the area to be burned and on surrounding areas.

All use of fire for removing brush, including the burning of piled debris, on California wildlands must be done by some sort of prescription, to assure effective burning under safe conditions. An official permit also is required for each burning operation during certain seasons as designated by law (Burcham 1959). And, within Air Quality Control Districts, special dispensation is needed for use of fire at any time of year in the critical job of removing hazardous fuels from wildlands.

Even though the conditions and procedures for burning are well prescribed, each burning operation should be handled by experienced persons. All of the art cannot be written into the prescriptions.

In prescribed broadcast burning, in order for the fire to move across the area to be burned, a relatively continuous ground cover of dry fuel—dead grass, pine needles, litter and duff, dry woody stems, or a combination of these ground fuels, must be present. Dry aerial fuel in upright shrubs also may be sufficiently continuous to help carry fire across an area. Fire may reach into the crowns of tall shrubs or trees and add to the intensity of burning, but fire does not spread across an area through the tree crowns under the conditions usually prescribed for burning. In fact, an element of the burning prescription may be to keep fire out of the tree crowns.

Three broad vegetation-fuel types may be defined for discussion of the uses of prescribed burning—grassy ground fuels, mainly dead grass; brushy ground fuels, mainly litter and dead woody stems; and timber ground fuels, mainly litter and duff, with dead shrub or tree stems. Burning objectives, appropriate season for burning, procedures, and environmental impacts all differ widely according to the vegetation-fuel type.

Prescribed burning has potential use for reducing fuel hazards under conditions such as those generally prevailing on California wildlands, yet it has not been widely used there strictly for that purpose. Programs of controlled burning aimed at multiple benefits on livestock and wildlife ranges, primarily on lands in private ownership, have been common. This burning, concentrated on foothill areas, has been done on woodlands having grassy ground fuels, but also on a large acreage of chaparral and woodland-chaparral with brushy fuels. From 1945 to 1973, a ranchers' controlled burning program under California Division of Forestry permit covered 2,534,000 acres (California Division of Forestry 1974).

Broadcast burning has been used most successfully for about 20 years in clearing dense brushfield areas being converted to grassland or, in a few instances, to pine plantations. For example, prescribed burning was used on much of the 28,500 acres of brushfields cleared on National Forest lands during the 1950's (Evanko n.d.). One definite objective of this clearing was to develop open areas as elements of fuelbreak systems to aid in wildfire control.

Broadcast burning also has been used in reducing slash on recently logged-over areas in northern California and the Pacific Northwest (U.S. Department of Agriculture, Forest Service 1972), but otherwise it has had very limited use within commercial timber stands in California. In a very limited way, prescribed burning has been used around timbered recreational areas (Biswell 1960; Biswell and others 1968), and in recent years a program of burning has been carried on to reduce fuels on federally-owned timbered lands devoted strictly to recreational uses (Kilgore and Briggs 1972; Schuft 1972).

The recent trend toward smaller individual "burns" increases greatly the number of burning operations needed if vegetation is to be modified on extensive acreages of wildlands. This, in turn, has compounded the problems in scheduling of burns during suitable weather with the manpower available for the job. If burns are scheduled in advance, as necessary when work is done cooperatively, with donated manpower, weather on the day of burning is often unsatisfactory for effective burning, or possibly hazardous, carrying the threat that fires may escape control. Burning with paid crews allows better scheduling but adds to the cost, in itself another limitation on widescale use of prescribed burning.

Experience in the ranchers' controlled burning program (Sampson and Burcham 1954), and in burning of brushfield areas on lands in governmental ownership, has shown that the cost of prescribed burning is considerable. Direct costs include manpower and equipment required for safe operations, and on livestock range, the value of grass forage consumed in each fire. Indirect costs include the probabilities of escape, overhead expenses of planning and administration, and direct detrimental effects (Zivnuska 1972). These costs are multiplied if repeated burns are needed to obtain satisfactory reduction of woody vegetation. An alternate course is to prepare the brush fuels ahead of burning, for good cleanup with a single burn under moderate burning conditions. Fuel preparation adds another cost in prescribed burning, but it is now a common practice in programs on both private and public lands—as the most efficient use of available money and manpower.

Watershed Effects

The advisability of prescribed burning as an over-all land treatment is open to question on many areas. For example, some public land managers are convinced that unburned shrubby vegetation is the best protective cover on steep watershed lands in southern California, even though extremely hazardous fuel conditions may develop when these lands are protected from fire (Dodge 1972; Hellmers 1962). The circumstances under which prescribed burning may be used on these lands have not yet been specified. Similarly, timberland managers in northern California apparently are not convinced that prescribed broadcast burning is a silvicultural practice adapted to high-yield, sustained timber production; perhaps they feel that alternate procedures are more effective and less expensive than the burning techniques used to date.

The potential effects of prescribed burning on the soil, and on erosion and flood hazards are difficult to describe. Burning of dense shrubby vegetation is a favored brush removal method because it produces minimum physical disturbance of the soil surface, yet wildfire burns in chaparral have resulted in great damage from erosion, deposition, and flooding (Sinclair 1954; Corbett and Rice 1966). Such damages, the result of intense wildfires during the dry season, are largely due to the complete denuding of unstable soils on steep slopes, augmented by intensification of nonwettable soil conditions. Prescribed burning—or any other brush removal treatment—obviously should be used with caution, if at all, on such areas, and entire steep slopes certainly should not be denuded at any one time. Gradual thinning of dense brush covers may be required.

Experts generally agree on the major soil effects of burning of vegetation. Broadcast burning of grassy ground fuels during the dry season does not greatly increase temperatures below the mineral soil surface (Bentley and Fenner 1958); the heat penetration depends mainly on quantity of grass consumed. The heat from burning grass persists for a very short interval, some litter usually remains on the soil surface, ample supplies of seed or crowns of perennial plants survive the fire, a new grass cover quickly regenerates during the next rainy season, and soil erosion is not of critical concern unless the area is heavily trampled. In contrast, burning of woody vegetation does increase soil temperatures when the soil is dry.[11] The soil is affected within a lens-shaped spot around each woody plant, or other woody fuel accumulation, that was consumed. Thus, some over-all impact can be expected if the consumed woody material was continuous, or if litter covers most of the soil surface. Intermediate effects occur after burning in open or semidense stands of woody vegetation.

Drastic changes in physical characteristics of the soil from burning of woody vegetation occur only in relatively small spots where logs or piles of heavy material have been consumed. After a fire these spots can be recognized by a deep layer of ash, discoloration of the soil, incineration of organic matter to a depth of 1 inch or more, and heavy charring below this level (Bentley and Fenner 1958). Burning of brush fuels—litter and stems—leaves a thin layer of ash which may soon disappear, leaving a bare soil surface. Charring of organic matter extends to a depth of about 1 inch, or less, below the mineral soil surface, indicating maximum temperatures up to about 350° F during burning. This so-called "soil-

[11] Bentley, Jay R., personal communication. Conclusions about soil temperatures during burning are based on his observations and measurements made during and after hot fires in mature chaparral, chamise types in the foothills, and manzanita brushfields in the mountains.

char" condition (Bentley and Fenner 1958) may cover much of the area after a hot burn in dense brush during summer or fall, on dry soil. Burning of semidense or light brush may leave a "surface-char" condition, with little charring below the mineral soil surface.

Typically, the postfire situation is a mixture of the two soil conditions after summertime burning of brushland. A protective cover of herbaceous plants develops slowly during the next year. If soil-char is dominant on an area, the bare soil is subject to erosion; sowing of grass seed is needed to develop a protective cover as quickly as possible. If surface-char is dominant, the natural regeneration of herbaceous plants may produce a cover within a year after burning.

An entirely different situation, not so commonly recognized and understood, occurs after burning of brushfields or in coniferous forest when the soil and lower portion of the litter are wet, as in burning during winter and spring, or early summer in the mountains. The damp litter and upper soil apparently provide an effective barrier against downward penetration of heat (Uggla 1958), even though intense heat is generated above ground during consumption of a dense woody cover. Observations after springtime burning of crushed brush—mature chamise in the foothills and mature manzanita brushfields at higher elevations—show that the soil has not been materially affected. Little of the organic matter below the mineral soil surface has been charred, and a thin layer of unburned litter remains on much of the soil surface. Few seeds of herbaceous plants survive to produce a protective soil cover, however. Broadcast burning while the soil is moist causes less soil disturbance than would occur from an equal degree of brush removal by any other method. Similar minimum soil effects have been reported from broadcast burning of timber ground fuels at times when the soil and lower portions of the litter or duff were moist (Schimke and Green 1970).

On areas having so-called "nonwettable" soils, burning of brush intensifies development of a relatively impenetrable layer below the soil surface. This problem exists on many steep southern California watersheds where soils are unstable and coarse textured; it is considered a primary cause of downslope surface movement of water and soil after the brush cover has been removed by wildfire (DeBano and Rice 1973). As outlined by DeBano (1969), before a fire the hydrophobic substances accumulate in the brush litter layer and in the mineral soil immediately beneath it. During a hot fire, the substances move downward along temperature gradients as heat from burning vegetation penetrates into the soil. After the fire, the water-repellent layer—intensified and thickened—occurs at a lower level in the soil. A wettable, easily eroded layer exists above it, apparently formed by the extremely high temperatures at the soil surface during burning, which destroy the hydrophobic substances and increase soil permeability. The temperature range under which the substances are intensified occurs in the upper inch of mineral soil under the soil-char postfire condition and at lower depths in the small spots where heavy stems have been consumed (Bentley and Fenner 1958).

The relation of heat penetration into the soil to intensification of water-repellent layers suggests two ways in which prescribed burning can be used to lower the possibility of increasing hazard from soil erosion: (1) burning of dense brush fuels when the soil is wet and heat penetration into the soil is minimal; and (2) conversion of brush covers to grass having a much lower fuel volume and limited heat production when burned.

Observations on many areas in California where broadcast burning has been used to remove dense brush from selected sites have not indicated serious problems from soil erosion. On these type-conversion areas, the slopes generally were below 30 percent gradient but included short slopes of steeper gradient having stable soils. Erosion problems, if present, were tied to improperly drained roads, trails, and bulldozed fire control lines. Erosion has been accelerated, however, by baring of the soil on long, relatively steep slopes. Wise site selection on areas of restricted size should allow prescribed burning without undue hazard of soil erosion.

Air Pollution

Atmospheric pollution is frequently the most general adverse effect from prescribed burning on wildlands. Smoke from burning vegetation, if it drifts over population centers, is a nuisance to many people, who may become highly critical of the burning program. Smoke filters out sunlight and reduces visibility; it can be a hazard to navigation of aircraft. Particulates in the smoke can be harmful to health under long exposure; however, the content of more noxious carbon monoxide, hydrocarbons, nitrogen oxides, and sulfuric oxides is very low, as compared to that in fumes produced by combustion of gasoline in vehicles (Darley and others 1966; Cramer 1968). Hall (1972) reviewed in depth the available information concerning air quality, and concluded that "the only penalty inflicted upon the environment by prescribed burning is a small and temporary decrease in visibility."

Smoke from a single burn is only a temporary pollutant of the atmosphere; yet prescribed burning on the scale needed for extensive manipulation of vegetation in California undoubtedly would produce more smoke than will be readily tolerated. At present, the burning is prohibited except by special dispensation in some districts, or in others is confined to atmospheric conditions which promote smoke dispersal into the upper atmosphere or away from population centers. These restrictions limit the number of days allowed for burning and can greatly reduce the total acreage burned, and possibly they may prohibit burning in some situations under conditions now prescribed for the safest effective use of fire. Perhaps more consideration can be given to balancing off a limited, though unpleasant, amount of smoke from prescribed burning against the risk of a much greater amount from the wildfires likely to occur if no prescribed burning is done. That is, reduction of hazardous wildland fuels through prescribed burning may well be given greater importance in the future.

Visual Effects

Another adverse effect of burning is the unsightly appearance of a recently burned-over area. Ash and blackened stubs give an appearance of devastation after an intensive cleanup fire which consumes most of the woody vegetation. The scorched, blackened, or charred shrubs and trees remaining after a less intense fire may be even more displeasing. This is a temporary effect, of limited environmental importance, but jarring to persons not trained to accept it as part of a planned program.

Evaluation

Prescribed burning has several plus values as a cultural treatment for removing and controlling woody vegetation. It usually costs less than other brush removal methods, except for small areas, where preparing control lines and assembling crews for burning can result in a very high cost per acre. Broadcast burning causes little soil disturbance compared to that from bulldozing or disking. Burning of dense brushy ground fuels prepares a clean seedbed for establishing a new cover. Burning of dry grassy ground fuels does not greatly disturb the protective soil cover; it regenerates at the start of the next rainy season.

Use of fire, instead of other cultural treatments, to modify vegetation is endorsed for general use by some environmentalists because fire originally was a "natural part" of the environment. But today, in most instances, we use prescribed burning in highly unnatural situations built up by modern man's use and occupance of the land. A major unresolved question is whether prescribed burning as the only vegetation treatment can possibly bring about satisfactory fuel conditions on millions of acres within a reasonable period of time. Perhaps the best procedure for making good progress in the near future, and in accomplishing the most successful long-term fuel modification, is in combining prescribed burning with other vegetation treatments. A combination of hand or mechanical operations and herbicide applications along with prescribed burning can be consistently effective, whereas the result of use of fire alone is apt to be rather erratic and uncertain. The remainder of this discussion describes aims and methods of prescribed burning in the three vegetation-fuel types.

Burning in Grassy Ground Fuels

In grassy ground fuels, dead grass mainly provides the fuel continuity, and burning commonly is done during the dry season after grasses have matured. Shrubs or trees are scattered or occur as thickets. The burning objective commonly is to kill scattered small woody plants, and to open up any shrub thickets, which contain some woody ground fuels. The primary burning objective may be removal of the grass itself, which is a hazardous fuel during the dry season.

Broadcast burning here may be aimed primarily at control of invading woody plants as part of a maintenance program. If the objective also is to remove shrubs or trees, the best and most widely accepted technique is to prepare these woody fuels for effective burning as described under "Burning Brushy Ground Fuels." The preparation is best done a year ahead of burning so that a new grass cover

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Figure 16.—Grassy fuels can be burned safely when some of the current year's growth is not quite dry, particularly if there is dead residue from the previous year.

becomes established to carry fire into the dead woody material.

Burning of grassy fuels must be done before the fall rains have beaten down the old dry grass and started growth cf new green grass that will dampen down the fire intensity. The burning also must be done at a time of day when the fine grass fuel is sufficiently dry to carry a fire of the desired intensity. Of course, this is also a time when vegetation on surrounding areas will burn readily. The hazard of escape is reduced by avoiding hot or windy weather, and usually burning before or after the hottest part of the day. The hazard is lower if burning is done during the spring, when some of the grass species are not yet completely mature and dry, and moisture content of fine green fuels is still above critical levels (fig. 16). A carryover of dry grass from a previous year facilitates this late spring burning.

Experienced crews can burn grassy fuels safely with rather narrow control lines—roadways, disked strips, or hand-cleared lines. But scattered accumulations of woody fuels within the area to be burned may produce glowing embers that carry downwind and start spot fires in dry grass across the fire control line. Any accumulations near the line should be burned out ahead of time under safe conditions. Firelines should be patrolled until all burning material has been consumed or extinguished.

Burning of grass as a fuel management practice in California commonly has been aimed at removing hazardous grass fuel during the current wildfire season. Such burning ordinarily is done under the safest possible conditions without specific attention to clearing away scattered woody plants. Therefore, techniques are not well developed for using grass fires both safely and effectively for actual killing of woody plants. The limits of fuel moisture and weather required for successful grass burning still need to be prescribed, in a form similar to those for burning brushy fuels, as described in the next section of this report. Some burning experience may be drawn on, however, to guide grass burning effort.

Cheatgrass (*Bromus tectorum* L.) ignites with a match when moisture content is down to about 30 percent (Mutch 1967) and burns increasingly well below this point. During burning tests in Utah on gently sloping plots (about 5 percent slope) when air temperature was 82 to 91° F, relative humidity 17 to 23 percent, wind variability 0 to 12 miles per hour, and fuel stick moisture 5.5 percent, the forward rate of fire spread was 42 to 56 feet per minute in cheatgrass.[12] Flames were 2 to 5 feet high.

[12] Benedict, Gene W., and Lisle R. Green. Ignition and rate of fire spread in grassland following cheatgrass reduction with atrazine. Unpublished manuscript on file at For. Fire Lab., Pac. Southwest For. and Range Exp. Stn. Riverside, Calif.

Wright and his associates in Texas reported that tobosa (*Hilaria mutica* (Buckl.) Benth.) and other grasses burned satisfactorily at moisture contents between 12 and 25 percent (Britton and Wright 1971; Stinsen and Wright 1969; Heirman and Wright 1973). They found that grass fire is very easy to control when winds are less than 8 miles per hour and relative humidities are between 50 and 60 percent. However, their grass burning to control woody vegetation was done at relative humidities of 25 to 40 percent. Fire burning in Lehmann lovegrass (*Eragrostis lehmanniana* Nees), with winds 3 to 5 miles per hour, relative humidity 39 percent, and air temperature 58° F, was "flashy" and burned 2.5 acres in 10 minutes (Pase 1971).

California annual grasses, burned to consume medusahead grass (*Elymus caput-medusae* L.), burned well at relative humidity 40 to 50 percent and temperatures 60 to 70° F, with downhill firing. A noontime temperature of 90° and relative humidity of 30 percent was too severe (Furbush 1953). However, in another test, McKell and others (1962) reported best burning conditions for consuming medusahead were experienced around noon with air temperature about 99° F, relative humidity 23 percent, and wind 11 miles per hour. The researchers also suggested evening burning, when relative humidity was 39 percent and air temperature 83° F.

Other experience in California suggests that about 40 percent relative humidity is the breaking point above which firebrands do not ignite dry grass.

Hot fires in a fairly continuous grass cover have been found to kill most new brush seedlings and established small plants of nonsprouting species. But burning of grassy fuels under moderate weather conditions does not usually kill well-established plants of sprouting brush species. Burning presumably will be most effective in killing sprouts during the afternoon, after radiation has raised surface temperatures of both the living plant tissues and the dead fuels—at times when the grass burning index is apt to be high. Examples can be found where hot wildfires in grassy fuels under extreme weather conditions have effectively thinned stands of sprouting chaparral, but we know of no examples of such success from planned prescribed burning.

Prescribed burning of vegetation dominated by grassy plants can be used for maintaining fuelbreak areas after most woody fuels have been removed. It has the additional advantage of fireproofing the fuelbreak during the current season, as an aid in controlling wildfires if they occur on adjoining areas. To date, however, burning has not been used for fuelbreak maintenance, perhaps because of the difficulties in assembling crews during the dry season and the hazards associated with burning at that time of year.

F-523565, 523566

Figure 17.—If a clean, safe burn is desired in mixed chaparral, the brush must be desiccated. Crushed brush (left) burns clean (right).

Burning in Brush Fuels

In brushy ground fuels, litter and dead woody stems on the ground are often sufficiently continuous to carry fire across an area at any time of year when the stems are dry and weather is favorable for burning. Upright dead stems help carry the fire. In preparation for burning, live stems may be killed to provide extra dry woody fuel. The burning objective usually is to remove all, or most, of the woody material.

Woody material may be gradually removed by repeated burning, but for several reasons the most feasible objective is commonly to remove all or most of it in a single burn. The litter and small dead aerial stems that have accumulated over many years provide good fuel which can be used to support a fire. Also, a single burn is more efficient, now that scheduling of days for burning and assembling of crews for repeated burns is increasingly difficult. Total costs of a single burn, including costs of fuel preparation, can be less than for partially effective repeated burning. Finally, complete brush removal by a single burn prepares the site so that equipment can be efficiently used if needed in establishing a new plant cover.

Longtime experience by ranchers and by governmental agencies in burning of brushland in its natural state—without prior fuel preparation—has shown that *heavy standing brush is seldom, if ever, satisfactorily removed by burning under prescribed weather conditions*. Fires burning in the litter and other small dead fuels may remove most green leaves and twigs, but will leave the larger green stems, and many patches of brush often will be missed by the fire. Consequently, methods have been developed for preparing brush fuels ahead of burning so that the woody material will be consumed in a single fire. An additional benefit of this fuel preparation is that brush can be effectively removed at all times of year under low-to-moderate burning conditions.

Preparation treatments.—The preparation treatments aim at killing and drying a sufficient number of brush stems or tree branches to promote consumption of any remaining green plants. Usually almost all of the aboveground parts are killed before burning, either by hand cutting the stems near the base or, most commonly, breaking and crushing the brittle shrub stems with mechanical equipment (fig. 17). The crushing also compacts the woody material into a relatively continuous fuel bed that is readily burned. Other fuel preparation treatments kill and desiccate the upright brush plants by herbicide applications without compacting the fuel bed. Equipment use and techniques for chaparral modification have been described by Roby and Green (1976).

Crushing is most effective in preparing brush stands dominated by shrubs having brittle stems—mature plants of chamise, manzanita, or various species of *Ceanothus*. Young plants of these species have limber stems which are not broken off

F-523567, 523568

Figure 18.—Two tractors (top), connected by an anchor chain, prepare to crush dense chaparral in preparation for burning, and (bottom) make a second pass in the opposite direction to uproot as much as possible.

by crushing. Old stands of brush species with tough stems, such as oaks (*Quercus* spp.), or with stems that are both tough and limber, such as bittercherry (*Prunus emarginata* [Dougl.] Walp.) and some other mountain brush species, are not effectively crushed.

A bulldozer, with the blade carried about a foot above the ground, is the equipment most commonly used for crushing brush. The objective is to snap the main shrub stems and not carry the plants along in front of the blade. The tractor walks over the broken-down brush and causes minimum soil disturbance. Although a narrow swath is covered, this is an efficient procedure when terrain and rocks allow the dozer to maintain continual forward progress. A bar can be attached to the dozer blade to widen the swath where terrain is gentle and relatively free of large obstructions.

An 80- to 160-horsepower tractor (D6 or D7 size) can crush medium brush on 2 to 3 acres per hour on favorable terrain, at a cost of $10 to $14 per acre. Crushing of heavy brush, or working on slopes with gradient in excess of about 30 percent, adds about 50 percent to the cost. Indirect costs of overhead, mileage, etc., are not included.

Use of an anchor chain increases efficiency where terrain is favorable and areas are of sufficient size to warrant assembly of the equipment. Pulling a heavy chain between two D7 or D8 tractors has worked well in mature brush on uniform terrain (fig. 18). Dodge and Pierce (1962) reported that two tractors could chain down 8 acres or more per hour on broad ridges, but only half that acreage where terrain was irregular. Forest Service experience suggests 1.5 to 6 acres per hour for two passes of the chain, one in either direction, in lighter fuels, and 1 to 5 acres in heavy brush. Costs for two passes of the chain averaged about $20 per acre in light brush on good terrain to $50 for the heaviest brush on steep terrain (Roby and Green 1976). One pass of the chain is frequently enough to prepare brush for prescribed burning, at proportionately lower cost.

Efficient "ball and chain" operations have been reported from pulling a large steel ball on a long chain behind a single tractor. The 58-inch ball, made of quarter-inch steel plate, is filled with gravel, water, or both, to a total weight of about 6,000 pounds. Most ball and chain operations are along ridges where a second tractor cannot operate, but Gilbert and Schmidt (1970) reported that a D-6C tractor worked efficiently in pulling the ball on a 150-foot chain over gentle terrain. The ball drifted downhill away from the tractor, or the tractor pulled away from the ball and around standing brush, and the chain crushed down the brush. Production ranged from 8 to 12 acres per hour with one pass of the chain.

The ball and anchor chain were used to greatest advantage on steep slopes in southern California National Forests. Results were good on relatively straight ridges, mostly free of large boulders, and covered with light-to-medium mixed chaparral. A large tractor on the ridgetop pulled the ball and chain across the slope. The ball dropped downhill, then edged uphill as it was pulled along, then dropped again. Two passes, one in each direction, were needed for good results. The upper ridge was left "clean," but degree of brush removal varied at the lower end of the chain. The net result was a desirable feathered effect at the lower edge of the fuelbreak.

Forest experience indicated that the ball and chain did not work efficiently on slopes with less than 30 percent gradient, nor on heavy chaparral dominated by oaks or other tough species. Frequent rock outcrops made ball and chaining difficult or impossible.

Various rollers and drags have been used with limited success in attempts to increase efficiency of the dozer blade alone (fig. 19). One compactor-crusher, the "Tomahawk," consists of a series of steel rings keyed in a spiral and mounted on an axle. Cutter segments protrude 2½ inches past the crusher segments of the rings. A 6-foot-wide model, attached to the blade of a D6 tractor, was tested on ponderosa pine thinning slash (Dell and Ward 1969). The degree of cutting and chopping of slash and mulching of woody material on and into the soil was

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Figure 19.—Various crushers and rollers have been used with the tractor. This 6-foot-wide experimental roller proved helpful for crushing mature brush inside the tractor treads and for forcing broadcast seed into the ground.

considerably greater than that achieved with a dozer blade alone. After one pass, the slash could be burned safely under prescription. After two passes, the fire hazard from slash was reduced to the point where additional reduction by burning was not planned. At today's prices, the work was done for about $25 per acre on gentle terrain, and $38 on uneven terrain having slopes up to 35 percent gradient.

The unpublished reports from trials of the Tomahawk in central and southern California for crushing brush species showed that it, like other mechanical equipment, produced best results in mature brushfields and on hard ground during the summer. Crushing was less successful during the spring. The crusher did not break down young, flexible brush plants in a satisfactory manner.

Brush that has been broken off and compacted near the soil surface can be burned much more readily than untreated upright brush. The compacted fuel can be burned within hours after crushing, but it is best left for a few weeks until the stems have dried to equilibrium moisture content. Dry crushed brush will be consumed under a low-to-moderate brush burning index, at times when green stems of untreated brush will not burn (Bentley and others 1971; Green 1970). Crushed brush can be burned under very unfavorable burning conditions when a moving fire cannot be generated in untreated brush. The firing crews can safely move through the crushed brush to set multiple ignition points if needed for developing hot fires in the prepared fuels.

Desiccation of upright brush for burning by applying chemicals has not been as widely used as brush crushing in California. Whereas crushing was a well-proven method, adapted to most of the areas where prescribed burning was being used for type conversion, the techniques for using herbicides as desiccants were not well developed until recent years. On many brushland areas now being considered for prescribed burning, the herbicide desiccants can be used more effectively, and at lower cost, than mechanical fuel preparation treatments.

Because herbicides for desiccating brush usually must be applied from the air, their use is restricted to locations where aerial spraying is a safe and accepted practice. Precautions in use of herbicides, and a discussion of the various types and formulations available are given below under "Herbicides." Here, only the two broad classes of chemical desiccants and their effects as fuel preparation treatments are discussed. The classification is based on the speed of reaction and the extent to which shrub stems are killed.

Quick-acting contact herbicides damage the plant tissues actually contacted by the chemical. Leaves and twigs having high surface/volume ratio are killed or otherwise damaged if exposed to the spray, but those within the shrub canopy may be little affected by aerial applications. In California chaparral the small stems greater than approximately ⅛-inch diameter are little affected by aerial application of contact herbicides (fig. 20).

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Figure 20.—A quick-acting contact-type desiccant will dry out leaves and smallest twigs, but does not affect moisture in larger stems.

Effects of contact sprays are temporary; new green twigs and leaves develop rapidly as soon as temperature and soil moisture are favorable for plant growth. In California this regrowth may start before the first fall rains; for example, at the North Mountain Experimental Area near Banning, Calif., new shoots 2 to 3 inches long were abundant on chamise stems in September among the dead shoots killed by a desiccant applied May 8. Thus, the quick-acting contact herbicides should not be applied far in advance of the planned date of burning.

The most important effect of contact desiccants is a quick drop in leaf moisture content, which occurs within a few hours if temperature is favorable. Maximum daily temperatures of 80° F, or higher, produce best results; below 60° F, the reactions are much slower. Moisture content drops while most leaves still have a green appearance, before effects of the herbicide are hardly apparent. Many, or all, of the leaves change color within one or two weeks, when moisture content of the discolored leaves and twigs has dropped to near the low moisture level in naturally dead leaves and litter. At this time the moisture content of small stems has not been greatly affected. For total fine fuels—leaves, twigs, and stems less that ½-inch diameter—alive at the time of spraying, the moisture content may still be approximately half that of the natural untreated vegetation (Carpenter and others 1970).

In dense chaparral containing dry litter and some naturally dead stems, a small decrease in moisture content of green leaves and twigs promotes burning under weather conditions unfavorable for burning the natural untreated vegetation. If leaves and twigs have been killed and have dried for a few weeks after application of a contact desiccant, flashy fires can be developed under a low brush-burning index. The previously dead litter and stems and the desiccated leaves and twigs will be consumed, but most of the green stems will still remain. Removal of total woody material is much less than from burning of crushed brush (Bentley and others 1971; Green 1970). Consequently, contact desiccants are not well adapted for preparing brush fuel ahead of prescribed burning if the objective is to remove the large woody stems. The contact desiccants do have a possible use, however, to promote burning under unfavorable weather conditions if only partial brush removal is expected from a single burn.

Contact herbicides used in desiccation trials on California chaparral include weed-killing oils, oils fortified with chemicals such as pentachlorophenol (PCP) or dinitro secondary butyl phenol (DNBP), cacodylic acid (dimethylarsinic acid), and paraquat (1,1'-dimethyl-4,4'-bipyridinium salt).

The unrefined or partially refined "aromatic" oils having a high content of polycyclic aromatic molecules are more effective than highly refined hydrocarbons as contact herbicides (Bronson 1954). Weed oils prepared by oil companies and low-grade diesel or diesel fuel oil have been used. Although effective against herbaceous weeds (Crafts 1955), the oils must be used in high volumes—50 to 100, or more, gallons per acre—to desiccate dense vegetation. Wagle (1955) found that such high volumes reduced moisture content of scrub oak, chamise, and ceanothus leaves and twigs by an average of 15 to 18 percent within a 6-hour period. Upchurch and Merz (1967) found that No. 2 diesel fuel at only 11.5 gallons per acre was ineffective or only slightly effective for desiccating privet (*Ligustrum amurense*) and ilex (*ilex crenata* var. *rotundifolia*).

The desiccating effects of oil have been greatly increased by fortification with phenol additives. Wagle (1955) found that 5 to 10 percent concentrations, by weight, of PCP in diesel applied at high volumes per acre generally doubled the 6-hour desiccation effect over diesel alone on chaparral species. He found that a 1 to 2½ percent concentration was about as effective as 5 to 10 percent. Upchurch and Merz (1967) reported that adding 2½ pounds of PCP in the 11½ gallons of diesel per acre increased desiccation of privet from 5 up to 65 percent and ilex from 0 up to 33 percent as compared to diesel alone. Increasing PCP to 5 pounds per acre produced little extra effect. Most of the desiccation occurred during the first 3 days following spraying.

Diesel fuel oil fortified with 0.5 to 1.0 percent PCP at a total volume of 20 gallons per acre is suggested for additional field testing in California, if a quick-acting desiccant is desired.

Cacodylic acid mixed in water is an effective quick-acting desiccant on woody vegetation. Applied at 12 pounds per acre it was one of the most effective leaf desiccants tested in tropical forests (Bovey and others 1969). Applied in May at 12.5 pounds in water to total 10 gallons per acre on mixed chaparral in southern California, it reduced moisture content of chamise leaves and twigs within 2½ weeks from 130 percent to 52 percent (Green 1970). Moisture reduction was somewhat less for scrub oak and birchleaf mountain mahogany (*Cercocarpus betuloides* Nutt. ex T. & G.).

Paraquat also has been used as a desiccant on woody vegetation in Texas (Bovey and others 1965) and in Puerto Rico (Bovey and others 1969). In northern California on a mountain brushfield dominated by greenleaf manzanita (*Arctostaphylos patula* Greene) about 4 feet tall, 4 pounds of paraquat in water at 5 gallons of solution per acre showed little effect for several days after application during cool weather in early June (Bentley and others 1971). With increasing temperatures one week after treatment, the leaf moisture dropped off rapidly. After 12 days, most leaves were dry and small stems were drying; dead material contained about 12 percent moisture but unaffected small green stems contained 70 percent moisture. For the total small fuel complex—leaves, twigs, and stems under ½ inch in diameter—alive at the time of spraying, the moisture content was still at 50 to 60 percent.

On the basis of cost alone, the PCP or dinitro solution appears more feasible for use as a quick-acting desiccant. A 0.05 to 1.0 percent solution in diesel oil would cost about $11 to $12 per acre for materials plus the cost of applying 20 gallons per acre by aircraft. Paraquat at a minimum of 2 pounds per acre costs at least $38.50 and cacodylic acid at 10 pounds per acre about $38 each for materials alone plus cost of applying about 5 gallons per acre.

Systemic herbicides, which are better proved than contact herbicides as desiccants on California brushfields, can be applied at less cost. When applied during the season of active plant growth, the systemics require a few more weeks than do contacts to develop the same degree of desiccation, but after additional weeks, or months, they produce a much more complete plant kill.

The slower acting systemic herbicides, such as 2,4-D, for maximum effectiveness, must move into the leaves and be translocated to growth zones throughout the plant. In woody vegetation the typical first effect is dying of leaves and twigs similar to that from contact herbicides, but occurring over a longer time period. During warm weather, leaves and small twigs may die and dry to a low moisture level within 6 weeks after application (Pase and Lindenmuth 1971), but reactions are much slower at other seasons of the year. For example, fall applications in mountain brushfields in northern California may not kill the leaves until the next summer (Bentley and Graham 1976a).

In contrast to contact desiccants, an effective systemic herbicide gradually kills the stems, or at least part of the stems, after the leaves and twigs have died. Plant dying progresses from the small stems to larger stems, and may continue until the entire plant, including the root system, has been killed; or the dying may terminate at any point on individual branches (Bentley and Graham 1976b). This process of dying requires several months, and additional time is required for the stems to lose moisture and dry to equilibrium moisture content (EMC) ahead of burning. In literature references, woody plants have been referred to as "desiccated" after leaves and twigs have changed color and have low moisture content, at a time when stems also may be dying. In reality, however, the plant is not fully desiccated until the dead stems also have dried. The total time period after systemic herbicides have been applied until stem desiccation is complete is determined by climatic conditions, the woody species in question, and the season of spray application.

In the brushfields of northern California, Bentley and Graham found that small stems of sprayed manzanita were dead, and larger stems were dying, by the first of October, at the end of the hot dry season (Bentley and Graham 1976a). This stage was reached within 4 or 5 months if spraying was done in May or June, but required about 12 months if spraying was delayed until September. In October, the moisture content of dead and dying stems was still nearly as high as in stems of untreated manzanita. The stems continued to die during cold winter weather. After snow had melted in the spring, the moisture contents of both small and large dead stems were between 10 to 20 percent of the dry weights. The brush was adequately desiccated for effective burning that would consume the standing shrubs almost as cleanly as on areas where the shrubs had been crushed down with a bulldozer (Bentley and others 1971).

Trials in southern California, where winters are relatively mild, showed essentially the same pattern of dying and drying of chaparral species as found for manzanita brushfields in the mountains (Bentley and Graham 1976b). Shrubs sprayed with systemic herbicides during the spring were partially desiccated by fall, but the stems had not died and dried until the next spring. At this time, however, regrowth of new green shoots was greater than for mountain brush species. A second spray may be needed for effective desiccation of foothill brush.

For both mountain and foothill chaparral in California, nearly a year is required to kill and dry the woody material after application of a systemic herbicide during the period of plant growth when it will be most effective. For shrubby vegetation the best spray season is from March to May in the foothills and May to early July in the mountains.

The pattern of dying and drying of woody vegetation after spraying of systemic herbicides is somewhat different in other climates. In tropical regions the systemic herbicides are most effective if applied during the season, or seasons, of high rainfall regardless of time of year (Tschirley 1968). Bovey and others (1969) found that systemic herbicides killed more of the leaves than did contact desiccants in dense tropical forests of Puerto Rico, although the systemics required 1 to 6 months for full effects. Regrowth of new leaves and twigs 6 months after spraying also was less where the systemics had been applied.

For this vegetation in Puerto Rico, Bentley and Graham determined that dying of stems progressed slowly and was less complete than for leaves and twigs, and that the time required after spray application for drying of the stems depended on time of spraying within the rainy season.[13] For example, ½-inch stems of guava (*Psidium guajava* L.) sprayed in May during the rainy season died and dried slowly down to EMC in November, a period of about 24 weeks after spraying. In contrast, on plants sprayed in early November near the end of the rainy season the small stems died and dried rapidly to EMC during the drought period, in a period of about 12 weeks. Killing and drying of both small and large guava stems—for burning during the dry season—appeared to be maximum on plots sprayed about 4 weeks before the start of the dry period.

The systemic herbicides used in California for control of brush regrowth, as described in the next chapter, are also used as desiccants. Bentley and Graham found that low-volatile esters of 2,4-D [(2,4-dichlorophenoxy)acetic acid] and 2,4,5-T [(2,4,5-trichlorophenoxy) acetic acid] were effective on both foothill and mountain brush species, and that addition of picloram (4-amino-3,5,6-trichloropicolinic acid) increased kill of some species (Bentley and Graham 1976a). Green and others (1966) found that addition of picloram killed more plants of chamise chaparral in

[13]Bentley, Jay R., and Charles A. Graham. Desiccation of guava and mixed hardwood forest by herbicides in Puerto Rico. Unpublished manuscript on file at the For. Fire Lab., Pac. Southwest For. and Range Exp. Stn. Riverside Calif.

southern California than did 2,4-D and 2,4,5-T without picloram, and that fewer plants had recovered 2 years after spraying on plots sprayed with picloram. Ryker (1966) in Idaho found that a mixture of picloram and 2,4-D amine produced 50 percent desiccation of topgrowth 6 weeks after a spring application as compared to only 17 percent for a mixture of 2,4-D and 2,4,5-T esters without picloram. Pase and Lindenmuth (1971) in Arizona found that a mixture of 2,4-D and 2,4,5-T esters desiccated leaves of turbinella oak (*Quercus turbinella* Greene)—mountain mahogany chaparral 6 weeks after application. Picloram is particularly effective on tropical vegetation.

Systemic herbicides at dosages ordinarily used in desiccant sprays on large chaparral shrubs do not necessarily kill all of the topgrowth; more green branches remain than after similar spraying of small seedlings or sprouts (fig. 21). But sprayed brushfields have been effectively burned if most of the stems had been damaged or killed by the herbicide. Spraying of systemic herbicides in late spring or early summer has produced consistently effective desiccation of mountain brushfields in California. Tests on foothill chaparral have been more limited and techniques are not fully developed, particularly for southern California. But techniques for using systemic herbicides as desiccants are sufficiently developed for trial use anywhere that this is an advisable method for preparing brushland fuels ahead of burning.

F-523571

Figure 21.—This chamise chaparral on the Los Padres National Forest was desiccated with 4 pounds of 2,4-D. Although there is scattered crown and stem sprouting, the brush will be consumed during a prescribed burn.

Brushland fuels can be prepared for burning by desiccation with systemic herbicides at costs comparable to those for brush crushing. For example, an application of 4 pounds acid equivalent (a.e.) of 2,4-D in 5 gallons of diesel oil per acre—an effective dosage on northern California chaparral—can be applied at a cost of about $14 to $15 per acre. Aerially applied desiccants will be cheaper for fuel preparation on areas where tractors cannot be used efficiently. Desiccant applications can be effectively used on relatively steep slopes and on rocky areas where tractors have limited use, and on brush mixtures containing limber stems not broken off by mechanical equipment. In some situations, a combination of brush crushing and aerial application of a desiccant will do a much more thorough preparation of fuels than will either treatment alone. Such situations occur where the bulldozers used in building fire control lines can be efficiently used to crush brush on part of the area to be burned, particularly on wide strips to be burned out adjacent to the lines.

Prescriptions for brush burning.—The prescription for burning an area of brush fuels spells out the objectives to be attained, the fuel preparation required, and the directions for conducting the burning operation safely. Although general guidelines and directives are used, a specific prescription is needed for each burn. Directions for a safe and effective burn take into account the terrain and fuel conditions expected on both the burn area and on the surrounding areas.

Commonly, the first weather element to be considered is wind direction. This may be dictated by terrain, natural flow patterns, or relative hazard of damage from possible escape fires on different sides of the burn area. Wind direction ordinarily is prescribed first, so that effort in clearing of control lines, which are built well in advance of burning, can be concentrated on the downwind or upslope sides of the burn area, or both.

The width of control line needed for safety in burning brush fuels ordinarily is decided by the experienced person in charge. In general, the line on the downwind side of the burn must be sufficiently wide to prevent preheating of fuels across the line, with resulting easy ignition. Under the usual prescribed fuel and weather conditions, the cleared lines around brush fuel areas are up to 100 feet or more in width on the downwind or upslope sides, and considerably narrower on other sides. If burning is to be done at the upper level of allowable fire hazard, some of the lines are widened by burning out strips of the brush area along the lines, during low-risk weather conditions ahead of the main burn.

The fuel and weather conditions prescribed for burning of brush fuels reflect specific limits in fuel moisture, relative humidity, air temperature, and wind speed that will allow control of the fire at all times, while meeting the objectives of burning. Experience in use of fire has shown that relatively safe conditions exist for effective prescribed burning, especially if fuels have been prepared ahead, if each of these elements is within the following range.

Element	Intensity	
	Low	High
Fuel stick moisture (percent)	15	5
Relative humidity (percent)	58	26
Wind speed (mi/h)	0	10
Air temperature (°F)	40	84

These elements, and slope gradient, interact so that their effects are compounded as the intensity of the elements increases. These interactions are expressed in terms of fire danger rating indexes. During field trials the index values were computed according to the California Wildland Fire Danger Rating.[14] The ranges in index values that allowed safe and effective burning to meet most objectives are:

Item	Intensity	
	Low	High
Fine fuel moisture (percent)	10	6
Spread index	4	17
Intensity index	28	60
Ignition index	5	52
Brush burning index	3	9

Additional field trials are needed to express these index values for prescribed burning in terms of the National Fire Danger Rating System (Deeming and others 1972), which takes into account some additional information on vegetation condition, slope class, and maximum and minimum temperature and relative humidity.

To a limited extent, trade-offs can be made between prescription elements (Buck 1971). For example, lower air temperature and higher relative humidity than prescribed can offset stronger, steady wind; or slope or firing technique can be used to advantage. The recommended limits provide a useful guide for experienced firemen, however, and should be exceeded only for good reasons.

If brushfield burning is done within the recommended limits for each index value, fires can be expected to burn slowly, if at all, in most natural untreated fuels. This greatly reduces the hazard of escape fires burning out of control and causing excessive damage. Even so, adequate control forces always should be on hand during the burning.

If brush fuels have been adequately prepared and are relatively continuous, they can be burned readily under the recommended brush burning index values. For example, Bentley and others (1971) successfully burned a series of treated plots in a manzanita brushfield under a low brush burning index value of only 4 or 5. Burning was done in the evening while fuel stick moisture percentage was still at approximately 7 percent but relative humidity was up to 40 percent, or higher, and wind speed usually was 0 to 5 miles per hour. Brush that had been crushed with a bulldozer or fully desiccated by herbicide treatment was fully consumed by hot fires. Hot fires also were developed in partially desiccated brush but the green stems were not consumed. Several ignition techniques were used successfully, including perimeter firing into the wind. No spot fires were started in heavy litter outside of the control lines, even though some plots were ignited in a manner which produced showers of glowing embers across the lines. Under the conditions described, the natural untreated brush could not be successfully burned, even with intensive ignition.

If a brushfield has not been prepared for burning, the prescription ordinarily specifies burning at near the highest recommended brush burning index value, and accompanying low humidity, high temperature, and highest permissible wind velocity. This increases the danger of spot fires across the control line, and larger fire control forces must be on hand. The degree of brush removal resulting from prescribed burning of unprepared brush fuels cannot be predicted. Generally, the dead woody material is burned and most of the green stems remain. Ordinarily the fire does not cover all of the area to be burned; many patches of unburned brush remain.

A variety of ignition techniques have been used for specific purposes in prescribed burning of California brushfields (Arnold and others 1951; Bentley 1967; and Schimke and Green 1970). Standard procedures are variations of line firing, but these can be augmented by more intensive ignition on portions of the area to be burned. One method of intensive ignition is setting of many closely spaced fires that support one another and quickly develop into a single hot fire that efficiently consumes dry woody material. This so-called "area ignition" can be used effectively to fire out a strip along the downwind or upslope sides of an area, before the fire is moved upwind or downslope by the line firing. The intensive ignition also may be needed for effective burning of small areas having sparse woody fuel under a low brush burning index. But area ignition at one time over all of a large brushland area is seldom either feasible or advisable. It can develop a conflagration that may move across a wide control line.

Brush fuels are usually ignited with drip torches or fusees, but butane torches also are very effective when fast firing of lines is needed. In crushed brush,

[14] The system used in the past by fire control agencies in California—developed by the California Division of Forestry, the U.S. Weather Bureau, U.S. Department of Agriculture, Forest Service, Region 5, and Pacific Southwest Forest and Range Experiment Station.

an area-ignition effect can be created by a crew using drip torches as they move in a line downhill or upwind across the area to be burned. It is an effective ignition technique for burning fuelbreak strips along ridgetops. Closely spaced fires also can be set by electrically controlled devices as described by Schimke and others (1969). Installation of wiring systems, however, is expensive and time consuming, and has limited application in practical brush burning. This procedure has best possibility for firing out sections of line where crews cannot be used safely, such as firing in depth along control line in dense standing brush.

Information on fuel and weather should be collected at the burn site 2 weeks, or longer, before the planned date of burning. The information can be correlated with data from fire weather stations to refine the fire weather forecast needed for the site on the day of burning.

Burning ordinarily is most safe and effective if started after the hottest part of the day, after brush fuel has been heated and dried during the day and when the declining brush burning index shows that hazards from possible escape fires also are declining. If the danger rating has been high during the afternoon, burning will be delayed until evening.

A small fire, located where it can be extinguished if necessary, serves as a final check on the burning prescription just before the main burn is lighted. An experienced observer can decide from fire behavior in the small test whether the burn is "go" or "no go" (fig. 22).

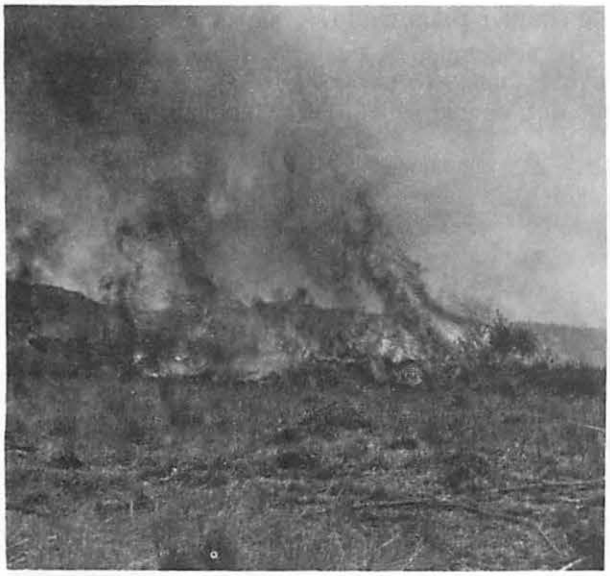

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Figure 22.—A small fire that can be extinguished if necessary should be used as a final check on the burning prescription. If the burning behavior of the test fire is satisfactory, the main burn area can be ignited.

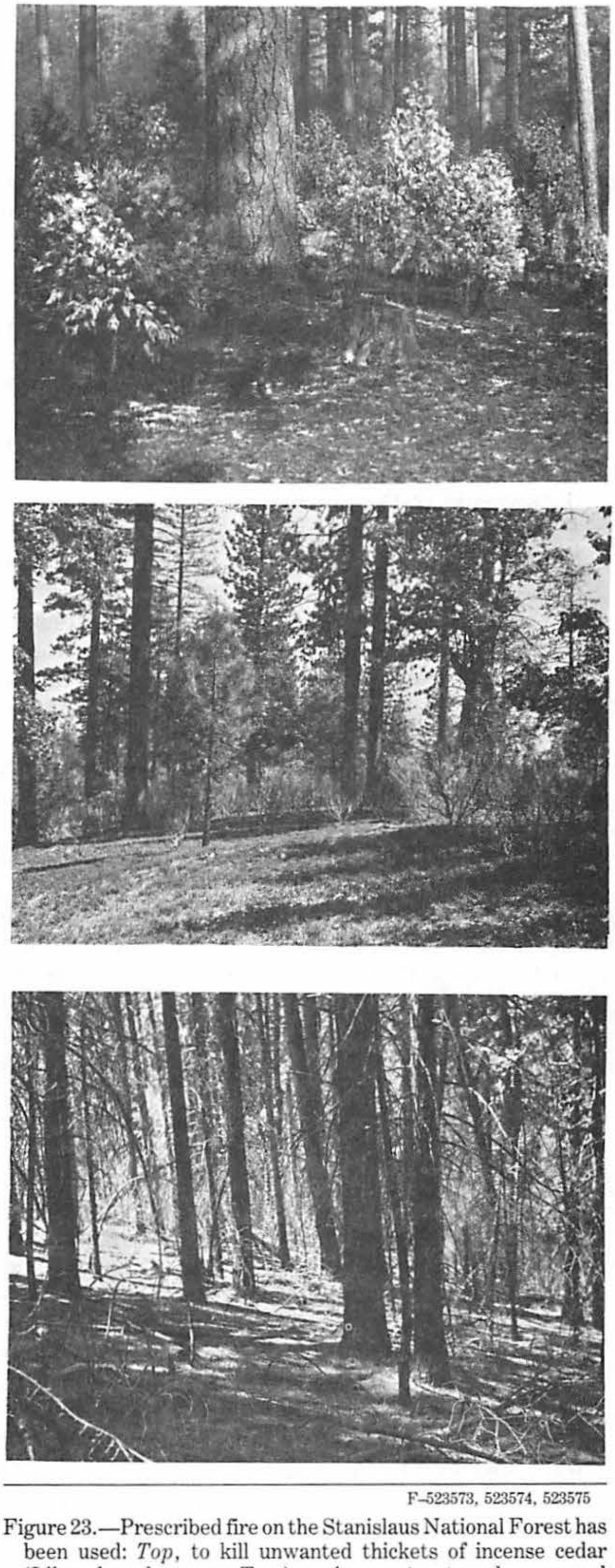

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Figure 23.—Prescribed fire on the Stanislaus National Forest has been used: *Top*, to kill unwanted thickets of incense cedar (*Libocedrus decurrens* Torr) or pine; *center*, to reduce ground litter and density of the bearmat ground cover, and kill susceptible shrubs; and *bottom*, to reduce density of an all-aged thicket. An additional burn several years later, after the small dead trees had fallen, made this area an effective fuelbreak.

Burning in Timber Ground Fuels

Prescribed burning in conifer forests as a fuel management practice aims at removing the understory fuels which, under wildfire conditions, may carry fire into the crowns of large trees (fig. 23). The immediate aim is to remove all accumulations of ground fuels—needles, litter, and debris—and to kill and consume most of the shrubs and any dense, frequently stagnated, stands of conifer reproduction. After this initial removal of hazardous understory fuels, the objective becomes control of woody plant regrowth and prevention of excessive accumulations of needles, cones, and dead branches on the ground. Prescribed fire for maintenance of fuelbreak areas is designed to keep the areas relatively free of small trees as well as shrubs.

In contrast to the hot fires usually generated in prescribed burning of dense brushfields, fires of relatively low intensity normally accomplish the initial removal of excess woody material within forested areas. On some high-value areas, such as intensely used recreational areas, much of the heavy woody material may be removed and burned in piles ahead of broadcast burning, so that most, or all, of the initial cleanup can be completed during one broadcast burn. This is a rather expensive operation with reported costs of $75 to $130 per acre in ponderosa pine forest (Green and Schimke 1971). More commonly, the aim is to accomplish the initial removal with a series of light broadcast burns, without fuel preparation ahead of burning. The open areas can then be maintained indefinitely by periodic burning.

In the Western United States, extensive use of fire as a fuel management practice has been confined mainly to ponderosa pine forests. Weaver (1952, 1967) reported that prescribed burning on Indian lands in Arizona and Washington, starting in 1942, reduced fire hazard within the ponderosa pine forests and also increased growth of the leave trees. Kollander and others (1955) credited prescribed burning of pine forest on the Fort Apache Reservation with an 82 percent reduction in number of fires, a 65 percent reduction in size of an average fire, and a 94 percent reduction in total acreage burned. Biswell (1959) in California reported that wildfires in areas previously burned by prescription were less destructive and much easier to control than fires in untreated areas. In the Southern United States, burning of pine forests has long been practiced to reduce fuel accumulations, to control disease and competition from undesirable hardwood species, to prepare seedbeds, and to improve habitats for both wildlife and domestic livestock (Dixon 1965).

Prescribed burning in ponderosa pine forests of California is still somewhat in the experimental stage. Definite prescriptions have not been determined for the many situations and different objectives of burning. Guidelines developed during studies of prescribed burning for fuelbreak construction and maintenance on the Duckwall Mountain area in the central Sierra Nevada aided in formulation of preliminary prescriptions.[15] These guidelines have been useful to the National Park Service in developing a broadcast burning program for recreational areas on public lands in California.

On the Duckwall area, the most abundant tree species is ponderosa pine. Incense cedar is next in occurrence. Other tree species of more scattered occurrence, but locally abundant, are white fir (*Abies concolor* Lindl. and Gord.), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), sugar pine (*Pinus lambertiana* Dougl.), and black oak (*Quercus kelloggii* Newb.). The most abundant shrub is whiteleaf manzanita (*Arctostaphylos viscida* Parry), which does not sprout from the root crown after burning.

The guidelines developed at Duckwall agree generally with the experience of other workers in California. To accomplish the objectives safely in ponderosa pine forests, the fire must be kept at a low burning intensity—flames generally not more than approximately 1 to 2 feet high. Firing should be from the top of the slope or into the wind at any time when fires burning upslope or with the wind will develop greater than the desired intensity of burning (fig. 24). Continuous wind from one direction makes firing simpler than wind that shifts in direction.

Burning must be done at a time when the duff layer is moist except for a dry upper surface. Most of the duff should remain after burning is completed;

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Figure 24.—Prescribed fire burning downhill or into the wind is less intense and more easily controlled than fire burning uphill or with the wind.

[15] Green, Lisle R., and Harry E. Schimke. 1970. Prescribed fire for fuelbreak clearing in the central California mixed conifer type. Data on file at the For. Fire Lab., Pac. Southwest For. and Range Exp. Stn., Riverside, Calif.

the remaining layer protects the soil and restricts establishment of new woody plant seedlings. Late winter or spring generally is the best season for burning, because more good burning days occur then. Heavy fuels are soaked after the winter snows, and generally do not burn or hold fire. Fall burning can be best, however, if the objective is to expose some mineral soil as a seedbed for new pine reproduction, or if large-diameter fuels must be consumed.

At Duckwall Mountain, the desired intensity of burning was generally achieved when the elements of fuel and weather were within these limits:

Element	Intensity	
	Low	High
Fuel stick moisture (percent)	20	6
Relative humidity (percent)	64	26
Wind speed (md/h)	0	10
Air temperature (°F)	20	84

When all elements were at low intensity, the fire would not burn with enough heat, but if all elements had been at high intensity the fire would have been too hot for easy handling and trees would have been scorched. Interactions of the elements as determined from the California Wildland Fire Danger Rating System show the following ranges in index values recommended for prescribed burning:

Item	Intensity Range	
	Low	High
Fine fuel moisture (percent)	12	5
Spread index	5	15
Intensity index	28	59
Ignition index	5	59
Burning index (timber)	2	8

Numerical values have not been determined in terms of the new National Fire Danger Rating System.

Burning was done safely with "cool" fires when the prescriptions were followed and full use was made of weather forecasts and local weather information. After experience and confidence were gained, a crew of three to five men equipped with a small tanker and hand tools could burn fuelbreak sites safely under the prescribed fuel and weather conditions. Test plots varied in size from 1 to 12 acres. Backup fire suppression forces always could have been called if needed.

Most of the tree and shrub stems under 3 to 4 inches basal diameter were killed wherever they were reached by the light fires. Of the conifers present on the plots, incense cedar was most readily killed. The fires injured very few trees as large as 6 inches basal diameter.

On plots burned three times in 4 years, the fires eliminated most woody stems less than 4 inches basal diameter, as well as much of the litter and debris. However, little dead material was on the forest floor for the third burn. Our recommendation now calls for one effective burn, then waiting until dead stems and other material have accumulated on the forest floor before repeat burning. The cleanup process may require several years. Burning is easiest on plots with continuous ground fuels such as pine needles, old grass, or bearmat to carry the fire.

Experience to date indicates that repeated prescribed burning, at intervals not yet determined, will open up fuelbreaks in pine forests and can be used to keep them open and functional (Schimke and Green 1970).

HERBICIDES FOR WILDLAND VEGETATION CONTROL

Herbicides may be applied in various phases of wildland fuel modification: preparing brushland fuels for burning; controlling regrowth of brush seedlings and sprouts after land clearing; reducing highly flammable herbaceous plants, such as annual grasses; preparing clean seedbeds in lands dominated by aggressive annual species; and maintaining clean firelines within fuelbreaks. Herbicides are particularly well suited for such use because they are selective and can be applied on rough and rocky terrain where some other plant control treatments are not feasible.

Use of other treatments commonly is limited or precluded by their poor adaptation to rocky soils or rough terrain, excessive disturbance of the site and the vegetative cover, inadequate control of aggressive plant species, or excessive costs. Herbicides, though less subject to such limitations, are seldom, if ever, used as the only treatment in management of wildland vegetation. They are most effective in combination with prescribed burning, browsing, or other treatments. Under certain conditions, the use of herbicides is inadvisable or is banned; hand or mechanical operations are then usually needed.

Herbicide applications for desiccating mature upright brush are not appropriate where mechanical operations can be used equally well. In expansion of prescribed burning onto rougher and rockier land, however, and in desiccating brush plants not readily broken off by equipment, broadcast herbicide application appears to be the only feasible method of fuel preparation. This treatment can make prescribed burning much more consistently effective in fuel modification on large acreages.

In controlling regrowth of brush plants on cleared areas, herbicide applications have been much more successful than alternative treatments, other than repeated hand cutting, in controlling brush seedlings and sprouts at a reasonable cost. Some resistant brush species, such as scrub oak, have not been consistently controlled, or control has been costly; yet herbicides have been more effective and efficient than other treatments. Selective herbicides are particularly effective in killing young brush regrowth while a new grass cover is being established, without damage to the new cover. Prescribed burning or browsing has not been effective in controlling brush sprouts, except on very small areas. Herbicide application can hold down early brush growth to a point where burning or other alternative treatments can be used effectively for maintenance. Herbicides can also be used for long-term maintenance of a low-volume plant cover.

For reducing flammable annual grasses within a perennial grass stand, the selective herbicides have been tested as a fuel modification treatment on limited acreage, and show some promise.

As soil sterilants for maintaining bare fire control lines, different chemicals have been tested for many years. Herbicide effects are somewhat temporary, so that their widespread use is limited. Alternative treatments—yearly baring of the soil by hand or with mechanical equipment—are used where feasible and not damaging to the site.

In preparing clean seedbeds for new perennial plant covers, herbicides may prove helpful on some sites where intensive cultivation with machinery would have excessive impact. Their use is described in the section "Establishing and Maintaining Ground Covers."

Environmental Implications

Herbicides must be used on wildland areas in accordance with Federal, State, and local regulations. These regulations have evolved from long experience in use of herbicides and from study of all other evidence of their possible deleterious effects. The regulations take into account the onsite effects and possible offsite effects from drift or other movement of the herbicides from the target area, along with the effects on humans and the total environment during handling and application. Various recent analyses show that approved herbicides, applied according to label instructions and local governmental permits, are not a significant hazard to the wildland environment.

Use of some pesticides, particularly chlorinated hydrocarbon insecticides, has been much deplored because of their persistence and their concentration in food chains. In contrast, most herbicides used on California wildlands have not called forth such disapproval; they are low in mammalian toxicity and have short persistence in the environment under most conditions. Conditions that favor high microbial activity are particularly destructive to herbicides—moisture, warm temperatures up to about 104° F (40° C), medium soil texture, and the presence of considerable humus. Soil reaction, rate of application, and dispersion through the soil strongly affect persistence of herbicides (Martin and Ervin 1970).

The approximate time required for disappearance of different herbicides from the soil under conditions generally favorable for microbial activity has been estimated (table 1). In our tests, the visible effects of herbicides applied at high rates as soil sterilants have persisted longest in arid situations. On sites receiving about 60 inches annual precipitation in northern California, the sterilants lost effectiveness in one or two years, even at heaviest rates. Experience was similar in North Carolina where monuron

TABLE 1.—*Expected persistence of herbicide effects in soil with recommended application rates*[1]

Herbicide	Application rate	Persistence expected
	Lb/acre, acid equivalent or active ingredient	*Months*
2,4-D	1 to 4	1 to 2
2,4,5-T	1 to 4	3 to6
Amitrole	4 to 8	1 to 2
Atrazine	1 to 3	6 to 24
	[1]10 to 30	24 to 36
Bromacil	1 to4	12 to 24
	[2]8 to 16	12 to 36
Dalapon	5 to 15	1 to 3
Dicamba	4 to 16	3 to 6
Diuron	1 to 4	6 to 24
	[2]12 to 48	24 to 48
Monuron	1 to 4	1 to 12
	[2]12 to 48	12 to 36
Picloram	1 to 4	9 to 24
	[2]10 to 15	12 to 36
Prometryne	1 to 4	3 to 6
Simazine	1 to 4	2 to 24
	[2]12 to 48	24 to 48
Fenuron	8 to 32	12 to 36
Tandex	12 to 24	12 to 36
Fenac	5 to 20	12 to 24

[1] Estimates are compiled from Martin and Ervin 1970, Lange and others 1968, and Montgomery and Norris 1970, and from experience within the Fuel-Break Project. Herbicides tend to persist longer in dry situations.

[2] At these rates, soil sterilization is intended.

(3-(p-chlorophenyl)-1,1-dimethylurea), diuron (3-(3,4-dichlorophenyl)-1,1-dimethylurea), simazine (2-chloro-4,6-bis(ethylamino)-s-triazine), and isocil (5-bromo-3-isopropyl-6-methyluracil) applied at 40 pounds per acre under 41 to 58 inches of rainfall, required a 20-pound retreatment each year to maintain an effective sterilization effect (Upchurch and others 1968).

Attention has centered on phenoxy herbicides, particularly 2,4,5-T, because of its extensive use and because of charges that 2,4,5-T had teratogenic effects—that it caused damage to unborn test animals. In response to these charges, the National Academy of Sciences prepared a list of scientists qualified to act as advisors to the Environmental Protection Agency (EPA) concerning phenoxy herbicides. A committee of 10, after reviewing all available information, submitted their report to the EPA Administrator on May 7, 1971.[16]

Findings of the committee were that "current patterns of usage of 2,4,5-T and its known fate in various compartments of the environment, including the plant and animal foods of man, are such that any accumulation that might constitute a hazard to any aspect of human health is highly unlikely." They recommended that registration for use of 2,4,5-T be restored to the status existing prior to April 1970, except for minor qualifications. One member of the committee, a biostatistician, objected that the committee may have underestimated dangers from unrestricted use of 2,4,5-T (Sterling 1971).

More recently, a detailed review by the Council for Agricultural Science and Technology [17] was made of the practical use of phenoxy herbicides, including 2,4,5-T, in the United States and of new evidence from laboratory studies. Their finding is that the principal hazard of the phenoxys is to nontarget vegetation that might be injured because of herbicide drift, and that the amount of dioxin in presently produced 2,4,5-T is not enough to endanger human health, or affect plants or animals.

Montgomery and Norris (1970) reviewed the literature and their own research, and concluded the hazard in the forest environment is low when 2,4,5-T is used according to recommended procedures. Degradation is rapid on the forest floor, and residues in streams are usually detected for only a few hours or days. This limited stream contamination is usually from spray drift or overflight during spray operations, and can be avoided. Concern about the use of herbicides on southern California chaparral and forested lands prompted a study of all information concerning the use of herbicides under arid situations. Incomplete information made conclusions tentative, but there was no indication of hazard to life from use of phenoxy herbicides in southern California.[18]

Harvey (1971) reviewed the effects of weed control on the environment, considering the problems of herbicide residues in soils, in water, in plants, in air, and in animal products, and concluded that there is no evidence that the use of herbicides in California today contributes to deterioration of our environment.

All herbicide use is under almost constant scrutiny by scientists, regulating agencies, and the interested public. Safeguards in herbicide use can be expected to change as new concrete evidence shows that restrictions should be eased or tightened.

Despite scientific evidence to the contrary, some people fear that herbicides may in some way be harmful to the environment, and they raise strenuous objections to any use of pesticides, failing to distinguish between those which are potentially dangerous and those which have no potential for harm. These questions and objections probably can never be resolved.

Other objections, including some legal actions, against use of herbicides on California wildlands appear to be aimed at the vegetation changes that result from herbicide application. The real issue here is the long-term objective of the vegetation management, rather than the assumed hazards of the herbicides. The objections should be resolved during land-use planning. After the desired changes in vegetation cover have been determined, herbicides can be used where they are the most feasible treatment for bringing about such changes.

Herbicides applied to wildlands may cause temporary onsite damage to native vegetation. Browning of needles or leaves on so-called "leave trees or shrubs," may be caused by direct application or by drift from indirect application techniques, but such slight damage soon disappears. Grasses and other plants resistant to the herbicides are not materially affected. Although scattered plants of choice browse species highly susceptible to the herbicide often suffer greater mortality than do less valuable species, this change is usually counterbalanced by a greater total amount of palatable young browse plants. In practice, herbicides would probably not be applied in management of brush stands dominated by choice browse species highly susceptible to the herbicide.

Herbicide applications can always cause offsite damage through drift onto susceptible vegetation

[16] Wilson, James G., Chairman. 1971. Report of the Advisory Committee on 2,4,5-T. Report on file with the Administrator, Environ. Prot. Agency. 75 p.

[17] CAST. 1975. The Phenoxy Herbicides Council for Agricultural Science and Technology Report 39. 21 p. Headquarters office, Dep. Agron., Iowa State Univ., Ames.

[18] Plumb, T. R., L. A. Norris, and M. L. Montgomery. Persistence of 2,4-D and 2,4,5-T in chaparral soil and vegetation. (Manuscript in preparation). Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

downwind from the target area. This effect is not a problem where the target area is surrounded by typical wildland vegetation remote from cultivated crops or ornamental plants. The small amount of herbicide that may drift across a narrow buffer strip onto a surrounding area causes little, if any, noticeable effect on typical wildland vegetation. Occasionally, however, susceptible native vegetation valued for esthetic reasons or as wildlife habitat is located near brush areas to be sprayed with herbicides. Special application techniques are then required, or the use of herbicides may be banned.

Safety Precautions in Herbicide Use

Before a pesticide (herbicide) is registered for use by the Environmental Protection Agency, it survives numerous manufacturer tests to establish its toxicology, its effect on animal and plant metabolism, and its behavior in the environment. U.S. Department of Agriculture, university, and other non-company research must confirm company claims. Upon product registration, the manufacturer prepares labels which present information needed to use the product with assurance of effectiveness and safety. If the product user reads the label, follows directions given, and observes the stated precautions and limitations, he should not experience serious problems in use of the herbicide.

Federal, State, and county agencies have established rules for herbicide use in their areas of responsibility. The Forest Service, for example, through its Pesticide-Use Coordinating Committees at the national and regional levels, monitors and regulates the agency's use of herbicides, and insures that they are registered for the intended use. County Agricultural Commissioners administer State and county regulations, and issue permits, which must be obtained before herbicides are applied on State or private land. It has been standard practice for the Forest Service to get a county permit before spraying on National Forest land too, a practice that should be continued.

Close supervision on the job is essential to insure that excessive drift does not occur, that sloppy work habits do not develop, that equipment is thoroughly cleaned after use (fig. 25). The supervisor should insure that all directions are carefully followed in handling the herbicides, and that they are stored at all times out of reach of irresponsible persons who might be harmed by the herbicides or who might commit vandalous acts. Proper protective clothing, if needed, and washing facilities should be provided for persons participating in herbicide applications. Empty containers must be disposed of in an approved manner. All other safety precautions applicable in handling and applying the herbicides should be strictly adhered to (Plumb and others 1963).

The one most important precaution is to make sure that the person responsible for herbicide application on the ground is thoroughly trained in all aspects of the work, and that the job is adequately supervised at all times. All available handbooks and other instructions for guiding proper herbicide applications should be studied.

A few herbicides not commonly used at this time on California wildlands present special hazards that should be understood by field workers. For example, sodium arsenite has high oral toxicity and is a great hazard to birds and animals. Its acute oral toxicity to small rodents is 10 to 50 mg/kg of body weight, compared to 300 to 1,000 mg/kg for 2,4-D and 2,4,5-T. Another dangerous chemical is sodium chlorate, which is included in some soil sterilants. An increased incidence of wildfire ignitions was detected in Los Angeles County from cigarettes dropped into dry herbaceous fuels which had been treated with a product containing sodium chlorate (Forman and Longacre 1970).

Herbicide applications near urban or agricultural areas are usually regulated by State and county officials. The regulations stipulate the locations where each herbicide can be used, the application techniques that can be employed, and the atmospheric conditions required for each method of application. If local regulations are lax in nonagricultural areas, the precautions in effect in highly regulated

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Figure 25.—Safety at all stages of a spray operation must be stressed. Here a crewman responsible for loading the helicopter ducks out of the way while the helicopter lands.

areas should nevertheless be observed. If all regulations and other precautions are followed, the hazards from offsite damage are very low. However, the land manager using herbicides will always be liable for any proven damages outside his own property.

Characteristics of Brush Regrowth

After brushfields in California are cleared, the native woody species aggressively reoccupy the site, regardless of the method of initial brush removal (fig. 26). The regrowth is typically from both old, vigorously sprouting plants and new dense stands of small seedlings, but in certain situations either seedlings or sprouts alone make up most of the regrowth (fig. 27). Control of this brush regrowth has been the most persistent and perplexing problem in manipulating vegetation on California wildlands—in converting brushfields to new vegetation covers or in maintaining thin stands of the native brush species. Sprouts from previously dormant buds on root crowns, stems, or roots left after initial brush removal have been most difficult to control, and here herbicide treatments may well be helpful.

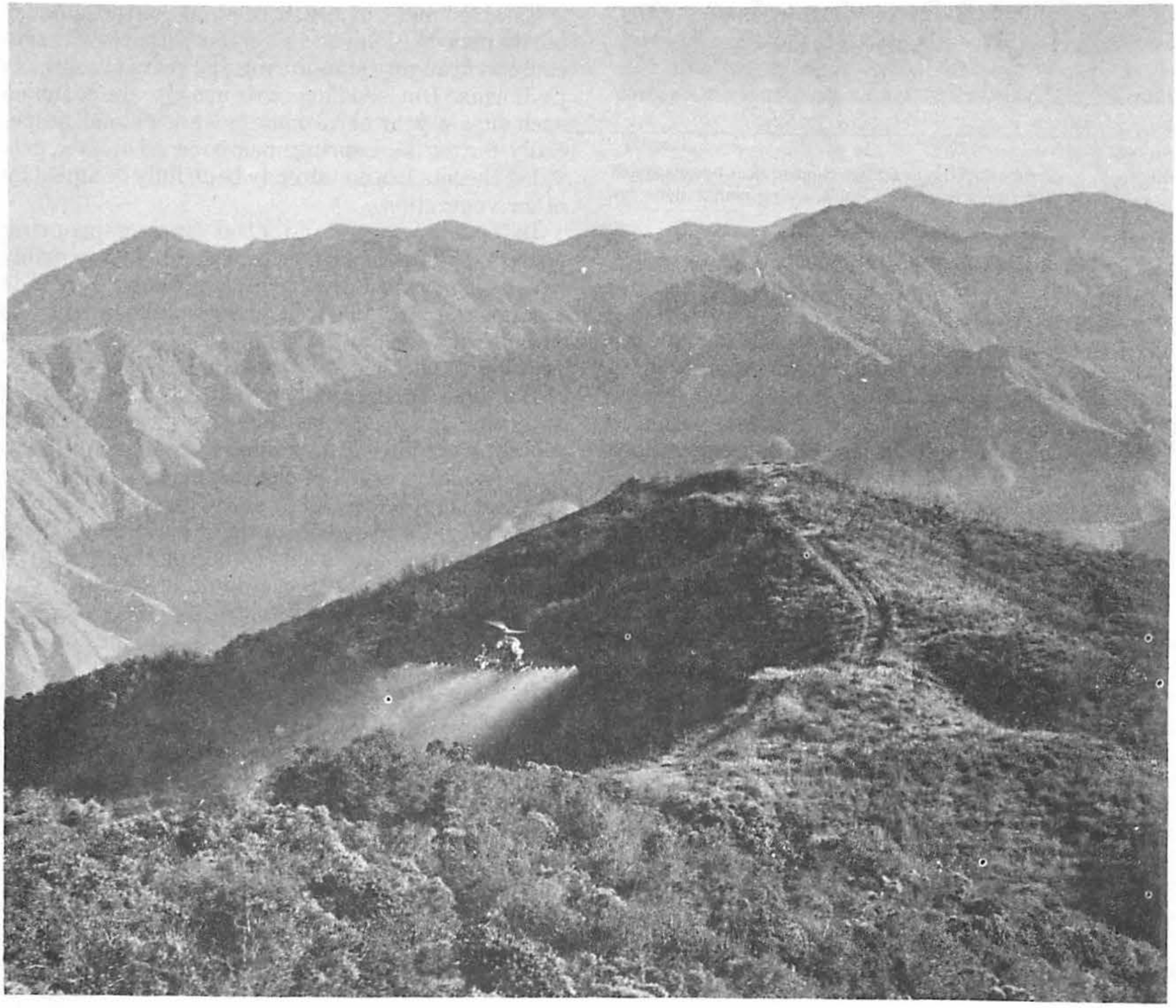

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Figure 26.—Brush regrowth is rapid during the years following removal of topgrowth by any method. Without immediate counteraction, such as the helicopter spraying shown here, fuelbreak clearing is nullified within a few years.

F-523579

Figure 27.—Shrubs speedily reoccupy cleared sites because most species sprout from the crown, but seedling plants alone can reestablish the stand.

Regrowth After Dry Season Burning

In southern California, sprouts of some species often start growing soon after burning of a brushfield. For example, after a fire in July, sprouts emerged from root crowns of many plants within 10 days, sprouts on some scrub oak and sugar bush sumac (*Rhus ovata* Wats.) were 8 to 10 inches tall within a month, and by December nearly all plants of laurel sumac (*R. laurina* Nutt.) and sugar bush sumac and about two-thirds of scrub oak, canyon live oak (*Quercus chrysolepis* Leibm.), and toyon (*Heteromeles arbutifolia* M. Roem.) had sprouted (Plumb 1961). Regardless of the early sprouting, however, the most vigorous growth of sprouts occurred during the next spring. The problem of brush control was complicated by delayed sprouting of some scrub oak plants during a long period of below-average rainfall which continued until 1964. Some plants remained dormant for 2 years after the 1960 fire (Plumb 1963).

In northern California, the brush plants normally do not sprout vigorously soon after a summertime fire, but growth of sprouts is heavy during the next spring and early summer. Sprouting is never delayed for years because of drought conditions.

Typical wildfire burning during the dry season in summer or early fall produces thick stands of brush seedlings during the next spring, when soil is moist and temperatures favorable for seed germination. Seed germination is promoted by the penetration of heat into the soil from burning at a time when the soil is dry (Bentley and Fenner 1958; Sampson 1944).

After summer or fall burning of dense brushfields, the first-year seedlings may become established in exceedingly high numbers: an average of 50,000 seedlings of all species on northern California areas (Sampson 1944); between 25,000 and 30,000 per acre of wedgeleaf ceanothus (*Ceanothus cuneatus* (Hook.) Nutt.) seedlings in Madera County in 1950 (personal communication, Jay R. Bentley, 1974); and about 40,000 per acre of all species at several locations in the San Gabriel and San Bernardino Mountains (Horton and Kraebel 1955). Most seedlings in such dense stands succumb during the first year, but sufficient numbers remain to produce future dense brush stands if the seedlings are not killed by some control treatment.

Establishment of brush seedlings after summer burns may be delayed in certain situations, especially on droughty sites during dry years in southern California. But seedlings are usually abundant on such sites a year or two later, when rainfall, especially during late spring, has been adequate, provided the site has not already been fully occupied by other vegetation.

In brush types dominated by nonsprouting species, the first surge of brush seedlings possibly can be controlled by burning without herbicide treatment, particularly if grass has been sown to provide dry fuel. If not burned, seedlings are susceptible to herbicides at this time.

Hot fires during the summer kill some plants of sprouting brush species, but the surviving plants reoccupy the site. For example, fire in chamise killed 50 to 70 percent of the old plants, mainly the weakest suppressed plants and plants with root crowns exposed to dead burning material, but the strong-growing plants survived in numbers of 1,000 or more per acre (Buttery and others 1959).

Regrowth After Spring Burning

Burning early in the year, while the soil and litter are moist, promotes rather rapid development of sprouts a few weeks after burning. In the foothills the topgrowth during the summer is somewhat sparse. But in mountain brushfields of northern California, burning in April produces a full stand of sprouts up to 1 foot high by early September.

Brush seedlings become established slowly after burning during winter or spring when surface litter and soil are moist. Heat does not penetrate into the mineral soil, and seed germination is not stimulated much by the burning. Most brush seedling establishment is delayed until the next year, or succeeding years. In the foothills, total seedling establishment tends to be very limited, compared with the dense stands that develop after dry season burning.

In mountain brushfields, however, rather dense seedling stands usually develop within a few years after spring burning, if seedlings are not killed by some control treatment.

In the foothills, brush regrowth is usually too sparse to warrant herbicide treatment at the end of the summer after burning in the spring. In the mountains the sprouts are large enough for spraying to be started in September, but herbicide control can very well be delayed until the next summer after more seedlings become established.

Spring burning kills few plants of sprouting brush species.

Regrowth After Mechanical Brush Clearing

Removal of brush with mechanical equipment greatly alters the pattern of brush reinvasion, by reducing or eliminating the plants of sprouting species and by spreading and covering brush seeds. The effects usually vary over any area, and the nature of the reinvasion differs greatly from area to area, depending on site, brush species, and severity of the mechanical operation.

Light bulldozing that scrapes off the brush plants with little soil disturbance leaves a stand of sprouting brush plants and a control problem similar to that after burning. Brush seedlings establish themselves slowly over a period of years.

Heavy bulldozing that moves large quantities of soil removes brush plants having small root crowns, such as chamise, ceanothus species, and some manzanita species—followup sprout control is no problem on areas dominated by such species. But most plants with tough crowns, such as oaks and chinquapin (*Castanopsis sempervirens* (Kell.) Dudley.), resprout after bulldozing. Species which resprout from broken roots, such as *Prunus* spp., increase in density and in the proportion of the brush cover they represent. These species not removed by bulldozing will need followup control if abundant on an area. Brush seedlings commonly become established in large numbers each year for several years after the heavy soil disturbance.

Disking reduces numbers of chamise plants and other species having small crowns, but has little effect in reducing brush species with tough crowns—followup sprout control is needed on most disked areas. Brush seedlings establish themselves much more slowly than on burned areas.

Available Herbicides

Herbicides available before 1945 had very limited application for control of brush on wildlands. A few were highly poisonous, others acted as soil sterilants in amounts required to kill shrub species, at least one presented fire hazards, others corroded the spray equipment, and some required very careful application to be selective in plant kill. The most suitable herbicides had to be used in large quantities and were not at all selective in plant kill (Harvey 1958). Ordinarily they were applied directly on the plants to be controlled or over small areas, where they killed or damaged all vegetation; broadcast application over large areas was neither advisable nor practical.

A series of herbicides made available since World War II opened the way for safe, effective, and practical control of brush regrowth on extensive areas of wildland. Because these so-called "hormone-type systemic herbicides" act on the plant enzyme system, only extremely small amounts are needed to kill or damage the plants. When the herbicides are used as directed, their actions are highly selective between plant groups—those now applied for brush control will kill or damage broadleaved plants, both shrubs and herbs, but have little, if any, effect on grasses. These herbicides are not persistent and do not sterilize the soil. The small amounts that are required can be applied at reasonable cost by hand, by ground rigs, or by aircraft.

The presently used phenoxy herbicides are manufactured as ester compounds, by combining the acid with an alcohol, and as amine salt compounds, by combining the acid with a compound containing an amino group (NH_2).

Esters

As broadcast foliage sprays, the low-volatile esters of 2,4-D or 2,4,5-T have proved more effective for killing chaparral species than the more volatile esters. The low-volatile esters, formed with long-chain, high-molecular-weight alcohols, vaporize slowly when temperatures are below 90° to 100° F, whereas volatile esters from short-chain alcohols volatilize readily at 65° F (Hoffman and Haas 1969). Use of volatile esters in most situations is inadvisable or illegal because of the danger from drift of the herbicide in gaseous form outside of the target area. The volatile esters are cheaper, however, and have been used in remote areas on easily killed shrub species, such as sagebrush (*Artemisia tridentata* Nutt.).

Low-volatile esters of 2,4-D and 2,4,5-T frequently used for brush control, taking their names from alcohols used in their manufacture, include butoxy ethanol, propylene glycol butyl ether, and isooctyl. The first two have been widely tested and used on California chaparral species. At least one test indicated that isooctyl ester was less effective at normally used dosage rates (Plumb 1963). Detailed comparisons of the different esters under a wide range of situations still have not been made, however. From limited tests to date, the differences in performance of various esters are more likely to be caused by formulation quality than by inherent differences in the esters themselves (Kirch 1967). The amount and kind of surfactant within the formulation can definitely affect spray results, especially from "low-cost" herbicides.

Amines

Water-soluble amines, and other salts, of phenoxy herbicides have been much less effective than the esters as foliage sprays for control of California chaparral species. The amine of 2,4-D is most effective when placed directly in the phloem tissue, in frills cut through the bark or by injection into the stem. The oil-soluble amines, now available, have not been widely tested as foliage sprays on California brush.

The amines are less volatile than ester compounds. Examples of amines in common use include alkanolamine, sopropylamine, diethanolamine, and dimethylamine.

Surfactants

Both oil-soluble esters and water-soluble salts used in oil-water emulsions for foliage sprays require the addition of surfactants to the formulations to produce stable emulsions and to improve spreading of droplets and penetration of the herbicide into the leaves (Kirch 1967). Surfactants are chemical compounds that reduce surface energy at very low concentrations (Bayer 1965). In the absence of surfactants, the droplets would form beads, because of the surface tension of water. Much of the spray material would run off slick or inclined leaf surfaces and stems, and the remaining beads would not penetrate through waxy or hairy surfaces.

Reputable herbicide manufacturers add sufficient surfactant to their formulations, but some products obviously contain inadequate amounts. The range needed in most herbicide solutions is 0.1 to 0.5 percent, or 1 pint to 2 quarts per 100 gallons of spray solution (Bayer 1965). If the spray solution contains enough surfactant, the droplets produce a light film on leaf surfaces immediately after spraying. If the droplets do not spread as a film, small amounts of surfactant—starting with only 2 ounces per 100 gallons of spray material—can be added until satisfactory leaf wetting is obtained. It is important to use the correct type of surfactant for each particular herbicide, which usually can be determined from the label on the surfactant or herbicide container. If other wetting agents are not available, most household detergents can be used.

Indications for Specific Herbicides

For the most common woody species on California wildlands, results of field tests are summarized here to show relative susceptibility of each species to the various herbicides, as listed by Leonard and Harvey (1965). These summaries have limited use as treatment guides because the plant associations are usually complex, composed of species that differ widely in susceptibility to any one herbicide. Also, the effectiveness of a herbicide depends to a large extent on the age of plants and their stage of seasonal development, on the method of herbicide application, and on the number of treatments to be applied.

2,4-D.—The first of the new systemic herbicides to be widely tested for control of woody plants in California, 2,4-D was enthusiastically received when it was released for trials in 1945. Considerable testing showed the low-volatile ester to be very effective on many chaparral species, and it remains the most useful of our chemical brush control tools.

The low-volatile ester of 2,4-D can be used, singly or in combination with other herbicides, as the basic chemical treatment for foliar spraying on young sprouts and seedlings of woody plants in California. This was demonstrated for some northern California species in a comprehensive test at three locations on mountain brushfields cleared by bulldozing in 1961.[19] As averages from all spray treatments, 2,4-D, 2,4,5-T, and a 1:1 mix of the two produced kills of 73, 74, and 72 percent for all sprouts and seedlings established by 1964 on all plots. For plots receiving the most intensive treatment—broadcast spray at 4 pounds acid equivalent per acre in three consecutive years, 1962–64—the average kills were 92 percent for 2,4-D, 97 percent for 2,4,5-T, and 97 percent for the 1:1 mix. The repeated spray treatment of small plants with 2,4-D killed sprouting plants and seedlings of the resistant species usually considered more susceptible to 2,4,5-T, including chinquapin, bittercherry, and snowbrush (*Ceanothus cordulatus* Kell.).

For aerial spraying on large areas of mountain brushfields, a relatively low cost 3:1 mixture of 2,4-D and 2,4,5-T was recommended for practical use (Bentley and Estes 1965). A mixture of 2,4-D and 2,4,5-T is effective for foliage spraying of sprouts and seedlings after removal of mixed chaparral at lower elevations. Use of 2,4-D alone has been very effective, however, on certain brush types dominated by susceptible species such as chamise, coastal sage, and big sagebrush. Current practice is to omit 2,4,5-T where 2,4-D will give satisfactory control.

[19] Bentley, Jay R., and Kenneth M. Estes. A test of repeated herbicide applications for controlling regrowth of brush on pine plantations in northern California. Manuscript in preparation, Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

2,4,5-T.—This herbicide has been tested almost as extensively as 2,4-D for control of woody plants on California wildlands. Low-volatile esters of 2,4,5-T generally have been rated as more effective than 2,4-D as a foliage spray on the hard-to-kill species. Both chemicals are effective once they are in the plant system.

The two herbicides have been widely marketed as "brushkiller" mixtures having 1:1 or 2:1 ratios of 2,4-D and 2,4,5-T, a.e., for control of mixed-species stands of woody plants. In California, the more expensive 2,4,5-T is seldom used alone as a foliar spray in situations where the cheaper 2,4-D can be combined with 2,4,5-T. In contrast, 2,4-D is often used alone in locations where it produces acceptable brush kill, even though a mixture might be more effective.

An exception to use of the two herbicides in a mixture occurs in broadcast spraying to control brush within stands of commercial pines, which are damaged more by 2,4-D than by 2,4,5-T. The mixture, or 2,4-D alone, is used to control brush during preparation of the site before planting of pines. But 2,4,5-T is used alone in almost all cases for so-called "release spraying" on sites occupied by pines (Bentley and Estes 1965). Any possible reduced kill of brush from use of 2,4,5-T alone is balanced off against reduced damage to the pines. In a few situations, however, where a dominant brush species, such as mariposa manzanita (*Arctostaphylos mariposa* Dudley), is highly resistant to 2,4,5-T but susceptible to 2,4-D, the application of 2,4,5-T alone is ineffective. Alternate techniques, such as spraying 2,4-D alone, need to be tested in such situations.

Current regulations require that 2,4,5-T not be used around homes, recreational areas, or where it may find its way into lakes or stream channels.

Silvex.—The early trials with silvex, 2-(2,4,5-trichlorophenoxy)propionic acid, for control of California chaparral species produced disappointing results, compared with those of the phenoxy acetic acid compounds. Consequently, silvex has been less extensively tested than 2,4-D and 2,4,5-T. Our observations of occasional limited tests confirm that silvex is less, or at least no more effective, than other phenoxy herbicides and will not replace either 2,4-D or 2,4,5-T for general use in control of brush regrowth in California.

Silvex has proved to be equal, or superior, to 2,4-D or 2,4,5-T in some tests, however. For example, it was superior in one study for control of woody plants dominated by blue oak (*Quercus douglasii* H. & A.) and poison oak (*Rhus diversiloba* T. & G.) (Leonard and Carlson 1959). Leonard (1960) also found that silvex killed more sprouting plants of interior live oak (*Q. wislizensii* DC.) than did a brushkiller mixture when applied in June, but was no better, or was less effective, at other times of year. Silvex ester at 4 pounds a.e. or more per acre was equal to a brushkiller mixture for control of salt cedar (*Tamarisk* spp.) (Range Seeding Equipment Committee 1966).

Picloram.—This herbicide became available for testing in California after techniques had already been developed for using 2,4-D and 2,4,5-T in control of brush regrowth on wildlands. Picloram as a potassium salt proved to be very effective on many woody species as a foliage spray, and on almost all species when injected into stems or applied as granules on the soil surface. An ester of picloram is available but has not been widely tested in California. Preliminary tests indicate that its effects as a foliage spray are similar to those of the salt. Its greatest promise at present appears to be in controlling some persistent brush species which have seldom been controlled in a truly satisfactory manner by either 2,4-D or 2,4,5-T, or where effects of these two chemicals have been highly variable from year to year.

Picloram has certain limitations which presently preclude its widescale use as a replacement for 2,4-D or 2,4,5-T in controlling regrowth of California woody plants. First, it is much more expensive on an acid equivalent basis; thus, it is not competitive for control of species susceptible to the other herbicides unless much lower dosage rates of picloram can be used. But for species not well controlled by 2,4-D or 2,4,5-T, use of picloram may well be cheaper than any other control method. Second, picloram is more persistent than the other two herbicides and its possibilities for use on watersheds in California have not been as well determined as for 2,4-D and 2,4,5-T. It should not be applied where it can enter ponds or streams. And, third, it is not yet registered for general use on rangelands grazed by livestock. Picloram has recently won approval of the California Department of Food and Agriculture for limited application on rangeland and permanent grass pasture, under the direct supervision of an employee of the County Agricultural Commissioner, or of the Control and Eradication Unit, Division of Plant Industry, California Department of Food and Agriculture. Certain restrictions regarding grazing of dairy or slaughter livestock, and application rate tied to acreage, must be observed. It is registered for use on rights-of-way, which allows restricted application on fuelbreak areas.

Picloram has proved extremely effective as a foliar spray for control of a wide range of woody plant species in many regions, particularly in tropical areas, where some tests showed it to be three to six times more effective than brushkiller mixes on an acid equivalent basis (Tschirley 1968). Tests to date in California have not indicated such wide differences in relative effectiveness on a pound basis, although relatively light concentrations of picloram have been very effective for hand spraying of individual plants.

Manufacturer research before picloram was released indicated that it was highly effective when hand sprayed at 2 pounds a.e. per 100 gallons of solution on some plant groups that occur in California. Picloram and 2,4,5-T ester were equally effective on manzanita, but picloram was more effective on some other species (Gantz and Laning 1963). Green and others (1966) reported complete kill of Eastwood manzanita (*Arctostaphylos glandulosa* Eastw.) from hand spraying of picloram. But, 2,4-D ester was much more effective than picloram as broadcast sprays for controlling greenleaf manzanita as young sprouts and as mature plants.[20]

Tests with picloram hand sprayed on sprouts of southern California shrubs, at light, medium, and high concentrations—1, 2, and 4 pounds a.e. per 100 gallons of spray material—showed that picloram was highly effective on both susceptible and hard-to-kill species. Most chamise was killed by one application at the light concentration, and all plants except scrub oak were killed at the high concentration. The high level was needed to kill Eastwood manzanita and laurel sumac. Red shank (*Adenostoma sparsifolium* Torr.), not readily controlled by the phenoxys, was killed at the medium concentration. Other species were partially controlled at concentrations from light to high. A single application, at any concentration, killed no more than one-third of the scrub oak plants. However, hand respray the following year killed surviving plants of all species receiving the medium concentration, except for scrub oak, which required the high rate (Green and Goodin 1965; Goodin and others 1966).

In southern California two broadcast foliage applications of picloram, in successive years, killed all sprouting plants of chamise and Eastwood manzanita when applied at a dosage rate of 2 pounds a.e. per acre, whereas less success was obtained with brushkiller. Yet, brushkiller killed one-third more scrub oak plants than did picloram in a more recent test (Plumb 1963, 1971). Unexplained variations in results are obtained with picloram as well as with the phenoxy compounds.

Amitrole (3-amino-1,2,4-triazole).—This herbicide is available as a water-soluble powder that has possibilities for occasional use on fuelbreak sites for control of poison oak and other sumacs (*Rhus* spp.). A recommended application is hand spraying at 2 to 4 pounds a.e. in 100 gallons of water. However, if the objective is to kill a variety of shrubs, brushkiller is considered more effective (Dunham 1965). Amitrole does not vaporize readily, but drift of fine droplets could damage downwind vegetation.

Ammate (ammonium sulfamate).—The best possibility for use of this corrosive material appears to be where hazard to adjacent sensitive vegetation precludes use of phenoxy herbicides. The ammate does not volatilize; as is true of all sprays, small droplets may drift with the wind onto nearby vegetation. Ammate dissolves readily in water, or an oil-water emulsion can be prepared with 6 ounces of emulsifying agent and 5 gallons of fuel oil per 100 gallons of spray solution. It is nonselective, and kills any plants sprayed, including many woody plants. In addition to corrosion, particularly of brass and copper, and possible drift, ammate is subject to use limitations because of the large quantities required—60 to 80 pounds per 100 gallons of spray, and 100 to 400 gallons of material per acre for thorough wetting of brush stems and leaves.

Dicamba (3,6-dichloro-o-anisic acid).—Dicamba has been used for control of a wide variety of herbaceous plants. It has also been tested alone and in combination with other herbicides for woody plant control, with variable results in California and elsewhere (Scifres 1972; Scifres and Hoffman 1972; Perry and Upchurch 1968). It seems to have no clear advantage over other phenoxy herbicides, nor picloram, either alone or in combination.

Methods of Application

Herbicides generally are applied as foliar sprays for controlling sprouting plants and seedlings of woody species, particularly if the plants occur in dense stands. Scattered individual plants in some situations are treated by spraying only the stems or stumps, or by direct injection of herbicide into the stem or stump. Some herbicides also can be applied to the soil for uptake by plant roots during the rainy season. Each application method has specific requirements of timing of operations and adherence to proper procedures. In fact, the application technique can be of equal if not greater importance than the choice of herbicide and dosage rate.

Application methods differ greatly in coverage of plant crowns, in entry of the herbicide into the plant system, and in dosage rates applied to each plant. Consequently, the effectiveness of a herbicide applied by one method cannot be related directly to that obtained by another method. For example, results from saturation coverage of foliage and stems by hand spraying do not predict results from low-volume broadcast foliar spraying of the same herbicide.

[20] Bentley, Jay R. Data on file at Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Broadcast Foliar Sprays

Broadcast application of a relatively low volume of spray material over all of an area is the most feasible method for applying herbicides in controlling regrowth of brush on wildlands. Large areas can be covered rapidly at a cost much lower than that incurred by hand applications on individual brush plants (fig. 28). Consequently, broadcast foliar sprays are applied where they can be safely used following removal of dense chaparral. In some situations the individual plant treatments are needed for followup control of the species most resistant to broadcast sprays.

Broadcast spraying has shortcomings which may prohibit its use on some areas, or require modification of techniques. Aerial broadcast spraying may be banned because of danger from drift of herbicide onto adjacent susceptible vegetation. It also may be objectionable because of damage to certain species, such as landscaping plants, on the area to be sprayed. Aerial spraying may be prevented by large trees left on timbered fuelbreaks. To solve such problems, the broadcast sprays can frequently be applied by hand-carried or machine-mounted booms moved around or under the shrubs and trees to be left on the sprayed area.

Application of broadcast foliar sprays at times when the woody vegetation is most susceptible to a herbicide is particularly important. The broadcast sprays should be applied during the most appropriate season, and in those years when plant age and size allows best coverage and kill by the herbicide.

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Figure 28.—Aerial application of herbicides is the only economical way to restrict regrowth of woody plants during conversion of watersheds, fuelbreaks, or other large areas from brush to other fuel types in rough terrain.

Seasonal timing.—Workers in woody plant control generally agree on the stage of annual growth during which brush plants are most susceptible to foliar applications of herbicides. To state this briefly, most, if not all, of the new sprouts and seedlings of the year should have emerged; most leaves on new twigs should be fully formed; and the plants should still be growing vigorously—before the leaves have started to "harden off" under moisture stress.

While leaves are still small, the translocation within the plant system is towards the growing tips of the twigs, which at this stage may be destroyed by a herbicide without transfer of the chemical downward through the plant (Leonard 1967). For example, sprays on blue oak were most effective soon after the leaves reached full size (Leonard and Carlson 1959). The sprays were less effective at a later date on older leaves, perhaps because the cuticle on leaf surfaces was more continuous and thicker than on younger leaves. The herbicide penetrates more readily into young leaves and enters the water phase inside the leaf (Bayer 1963).

Active shrub growth takes place only if soil moisture is available to the plants, but moisture availability is not directly observable. Workers generally agree that broadcast sprays are progressively less effective during the dry season as stored soil moisture is depleted. Jones and Laude (1960) found that moisture content of new chamise growth increased rapidly during the period of growth rate acceleration and declined at the time of rapid starch depletion, when growth rate was highest. Laude and others (1961) found that the shoot growth of chamise reached 3 inches in length, the point at which moisture content peaked and started to decline, in late May in northern California during 1956–57; two years later moisture reached this peak 7 weeks earlier. All observations indicate that spray treatments should be timed to correspond with a period of high twig moisture content, but the date varies with yearly weather and with other factors not so readily evaluated.

Active shrub growth requires favorable air temperature as well as adequate soil moisture. In tropical areas having favorable temperatures year long, the effectiveness of a herbicide application on woody vegetation is determined to large extent by the amount of precipitation received during a few weeks before and after spraying. In California—where most of the precipitation falls during months when temperatures are below optimum for plant growth and when day length is short—woody plant growth does not reach a peak until near the end of the rainfall period, or shortly afterwards. In the foothills, where winters are relatively mild, new twig growth starts during the fall or winter and reaches a peak during the spring, but considerable variation is caused by inherent differences between woody plant species and by year-to-year differences in temperature and rainfall. In the mountains, where winters are cold, twig growth proceeds rapidly during late spring and early summer.

In both the foothills and mountains, brush regrowth in spring has been depleting soil moisture stored during a preceding period of heavier precipitation before broadcast sprays are applied. The speed of soil moisture depletion—and the date when the plants will come under moisture stress—depends in part on amount and distribution of yearly precipitation, but it is influenced greatly by age, size, and total crown density of the brush plants. A dense stand of young first-year brush regrowth—either small sprouts from old established root systems, or seedlings—does not deplete the stored moisture nearly as fast as does a dense stand of older and larger sprouts or seedlings. Thus, best spraying dates are later in the season for young regrowth, and proper timing may be less difficult than for older vegetation, especially in the drier regions where moisture depletion occurs during a short period.

The best spray date in any year depends on the age of brush regrowth and on the extent to which it has been kept in check by other treatments. For example, after spring burning of a manzanita brushfield in northern California, sprouts which had grown during two summers were at a stage for spraying before August 1, while sprouts reduced in stature by spraying at the end of the first summer were not sufficiently developed for spraying until after September 1 during the second summer.[21] Tests in southern California showed that 2-year and 3-year-old chamise sprouts were best controlled by spraying a few weeks earlier than the best date for small 1-year sprouts (Plumb 1969).

In mixed stands, the best date for spraying in any situation must be determined by growth of the dominant species, or by the species most resistant to the herbicide. The date of maximum growth rate may differ several weeks between different species. For example, in southern California two species of *Adenostoma* showed different growth patterns: chamise grew slowly during the winter, increased growth tempo in March, grew most rapidly in May, and nearly stopped growth activity by mid-July; but red shank did not start obvious growth until February and did not reach its period of most rapid growth until mid-June (Hanes 1965). Such variations in growth pattern in some situations can allow adjustment of spray dates to favor survival of desired species while controlling undesirable ones.

In broadcast spraying to control brush regrowth within pine plantations, some compromise on application date must be made to obtain effective brush control with minimum damage to the pines. Small ponderosa pine is relatively resistant near the end of the summer dry period—approximately September 1—when metabolic activity appears to be at a low level (Bentley and Estes 1965; PNW Annual Report 1971). Young brush regrowth, to about 2 years of age, is still fairly susceptible to broadcast spray at this date. But the brush becomes less susceptible if it is allowed to grow a few years before spraying; more repeat sprays are usually needed to obtain the desired level of control.

Spraying of pine plantations in California can be rather easily scheduled near September 1 in any year because hot, dry weather consistently occurs during the preceding few weeks. In contrast, at other times of year the weather is uncertain and growth stage of pine cannot be easily predicted, particularly in early spring. Attempts at spraying in early spring before elongation of pine buds had started, when pines were assumed to be dormant, showed that metabolic activity actually had started and the pines were subject to more damage than when sprayed near the September 1 date (PNW Annual Report 1971). Observations in 1962 showed damage from November spraying after heavy October rains had stimulated metabolic activity in ponderosa pine plantations.

Timing by years.—Although seasonal timing of broadcast foliar sprays is always critical, the most consistently successful control of brush regrowth on California wildlands has been achieved by spraying during the years when the sprouts and seedlings are most susceptible to herbicide applications. Briefly, for best results, the first spray is applied while the brush plants are young and small, and at least one or two repeat sprays are applied during the next few years.

Workers generally agree on the advisability of starting the spray applications during the first or second year after initial removal of brush topgrowth by burning or mechanical treatment. Small seedlings and sprouts are easiest to kill, provided the twigs and leaves are fully formed and soil moisture is adequate. Susceptibility to sprays usually decreases with each year as the plants increase in age and crown size. Seasonal timing of sprays and adequate coverage of plant crowns become difficult, and treatment results erratic, after the plants have regrown 4 or 5 years, or longer. Spraying dense stands of mature plants does not usually produce consistent total plant kill, even though such spraying can be satisfactory in preparing fuels for burning.

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[21] Bentley, Jay R. Data on file at Pac. Southwest For. and Range Exp. Stn., Berkeley.

There is better kill of plants when they are young and small for several reasons. Leaf cuticles are less developed, and herbicides can penetrate more easily into the leaves. The limited amounts of herbicide applied in broadcast sprays provide better coverage of all leaves on small plants than they can on the densely foliaged crowns of larger plants. Equally important, the limited foliage of small plants extracts soil moisture slowly and allows a longer effective spray season, but moisture use is rapid and there is a short, critical spray season in dense stands of larger brush.

The decision to delay the first spray until the second growing season depends to some extent on brush species and site, but date and method of brush removal usually determine when spraying should start. On areas cleared by burning during summer or fall, or by mechanical treatment any time during the calendar year, the vigorous brush sprouts are ready for spraying during the next spring or early summer. At this time, the current crop of brush seedlings has emerged, although new crops of seedlings can be expected for a few more years after mechanical clearing. Spraying during the first season after brush removal is particularly needed to control sprouts of the most rapidly growing species, such as live oak and tanoak (*Lithocarpus densiflorus* (H. & A.) Rehd.). For all species, the first broadcast spray is less effective if delayed past the second growing season after land clearing.

Soon after burning of brushfields during the spring—near the start of the main plant growing season—the brush sprouts may grow vigorously, but most seedlings do not emerge until the next year, or later. By the end of the first growing season, only a few months after burning, the sprouts may be sufficiently developed for spraying. For example, after burning of a manzanita brushfield in the northern California mountains in April, the sprouts were effectively sprayed in early September.[22] Some species, however, such as chinquapin, grow slowly the first season and can be more effectively sprayed the next year. Excellent control of all species has been obtained on plots where the first spraying was delayed until July or August of the second year after springtime burning of northern California manzanita brushfields.

When the first broadcast spray has been applied during the first or second plant growing season after removal of dense brush, one or more repeat sprays almost always have been needed to obtain the desired level of brush control. The first spray job seldom produces adequate control. When the first spray was delayed a few years and brush regrowth became well established, the first spray usually produced limited results and repeat spraying was essential.

Planning for two repeat broadcast sprays appears advisable in most situations. The second repeat spray need not be applied if the remaining brush will not compete strongly with the new vegetative cover, either grass or pines, or if the brush is being held well in check by browsing of wildlife or livestock. Any brush control desired after three broadcast sprays probably can be accomplished better by some treatment other than broadcast spraying. At some later date, however, an additional broadcast spraying may be a very effective maintenance treatment.

A comprehensive study of repeat spraying after brush removal in 1961 at three locations in the northern California mountains produced results and conclusions considered generally useful in selecting the best combinations of years for spraying.[23] For those sprouts and seedlings present in 1962 when spraying was started, two consecutive treatments in 1962 and 1963—either broadcast sprays or hand spraying—adequately controlled the relatively susceptible species, such as deerbrush (*Ceanothus integerrimus* H. & A.), greenleaf manzanita, snowbrush, and root sprouts of bittercherry and sierra plum (*Prunus subcordata* Benth.). The more resistant brush plants, such as seedlings of whiteleaf manzanita and sprouts of chinquapin, required three sprays in 1962, 1963, and 1964. Three sprays also were needed on all bulldozed brushfield plots to kill the many new brush seedlings which became established each year until 1965. One spraying in 1962 killed 56 percent of all brush plants, including the new seedlings, two sprays in 1962 and 1963 killed 60 percent, and three sprays in 1962, 1963, and 1964 killed 89 percent. Broadcast sprays were more effective than hand applications because many small seedlings were missed each year during hand spraying. The three sprays would have been more effective if the last one had been applied in 1965 to kill the seedlings established that year.

The three sprays reduced numbers of brush plants to a low level—less than 200 per acre—on a burned timber site. But, many small brush plants remained on most of the plots in bulldozed brushfields—about 1,000 per acre, plus those established in 1965. Even though surviving plants had the potential for producing a new stand of brush in the future, their competitive effect had been greatly reduced by either two or three sprays. For example, the plots receiving three sprays had less than 1 percent as much brush crown volume in 1966 as on unsprayed plots, and plots receiving two sprays had about 3

[22] Bentley, Jay R. Data on file at Pac. Southwest For. and Range Exp. Stn., Berkeley.

[23] Bentley, Jay R., and Kenneth M. Estes. A test of repeated herbicide applications for controlling regrowth of brush on pine plantations in northern California. Manuscript in preparation, Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

percent of the crown volume found on unsprayed plots.

Dosage rates.—Workers generally agree that 2 to 4 pounds a.e. per acre of phenoxy herbicides are required for effective control of brush regrowth by broadcast spraying on California wildlands, assuming proper seasonal timing of applications and repeated spraying as needed. The 2-pound rate has been effective on the smallest plants and most susceptible species, but 3 or 4 pounds has given better control in most situations. Where rates up to 8 pounds produced even greater kill from a single application, spreading this amount over repeated applications in consecutive years appeared to be much more advisable. Single applications at extremely high rates applied on experimental areas did not kill the most resistant brush species, and were far in excess of requirements for susceptible species (Plumb and others 1966).

Observations of spraying both chamise sprouts in the foothills and deerbrush seedlings in the mountains showed that effects from the heavier dosage rates in broadcast applications were determined largely by the size and density of individual plant crowns (Plumb and Bentley 1960 and Bentley and Estes [23]). For each of these two susceptible species, the smaller plants with open crowns were readily killed by approximately 2 pounds per acre of phenoxy herbicide, yet this dosage killed only the upper part of the crown foliage on vigorously growing plants with thick crowns. Doubling the dosage rate killed more of the foliage and more plants: for chamise an increase in rate from 2.6 to 5.2 pounds increased the kill from 18 up to 65 percent. Similar results were obtained on deerbrush by increasing the rate from 2 to 4 pounds. Another doubling of rate, up to 8 pounds, killed almost all of the densely foliaged deerbrush plants with a single application. However, equally good kill was obtained by repeat sprays at lower rates—a more advisable practice.

In the comprehensive study of repeat spraying at three mountain locations [23] on a burned timber site, the brush mixture containing seedlings of whiteleaf manzanita was less well controlled by the 2-pound rate than by heavier rates. For all species, two consecutive sprays produced an average kill of 54 percent at 2 pounds, 92–94 percent at 4 pounds, and 93 percent at 8 pounds. Three sprays produced 88 percent at 2 pounds, 96 percent at 4 pounds, and 99–100 percent at 8 pounds. On bulldozed brushfields dominated by small greenleaf manzanita seedlings instead of whiteleaf manzanita, the 2-pound rate was nearly as effective as the two higher rates when applied in consecutive years.

In broadcast spraying of 2,4,5-T to control brush within pine plantations, a dosage rate of 3 to 4 pounds a.e. per acre has commonly been used (Bentley and Estes 1965). Lower rates were not advised because brush regrowth was being sprayed later than the best seasonal stage, it commonly had grown at least two years between sprays, and it had become more resistant to herbicides. A rate of 2 pounds per acre was effective in consecutive annual sprays on the smallest plants, but it often produced little observable effect on older, well-established brush regrowth.

A label restriction on 2,4,5-T now limits its use on ponderosa pine plantations to a maximum rate of 2 pounds a.e. per acre. Use at this rate in many situations in California will produce unsatisfactory results. Application of this low dosage may prove to be a questionable practice that wastes both herbicide and effort, allowing undesirable growth of competitive brush that becomes increasingly more difficult to control.

Analyses of results from plot tests and practical applications in California since 1962 indicate that 4 pounds per acre of 2,4,5-T is well within the tolerance level of young ponderosa pine.[24] In fact, in only one year on only one forest did 4 pounds produce damage above acceptable levels, and this damage could not be related to specific causes. In plot tests, 2,4,5-T at a rate of 4 pounds, and greater, was applied over young pines of different ages, from mid-August to mid-October, with limited, or negligible, damage to the pines. Damage was caused more by overlap of boom swaths than by dosage rate per acre.

Spray techniques.—Broadcast sprays must be carefully applied to obtain uniformly effective brush control without damage to other plants, such as young pines or landscaping trees or shrubs, on the area to be sprayed, and to prevent drift of herbicide onto adjacent areas.

Information is available on procedures for mixing and handling of herbicides, calibration of equipment, application of uniform swaths, and on special precautions to be taken in applying all herbicides. Licensed commercial applicators of herbicides are trained and experienced in techniques for safe and effective broadcast applications, but the land owner or manager should oversee the operations and make sure that proper procedures are followed.

Although aerial application of broadcast spray is the most feasible method on extensive wildland acreage, hand-held or machine-mounted booms can be used to advantage on many areas (fig. 29). These alternate methods reduce the hazard of herbicide drift, can be used effectively under and round trees or large shrubs, can overcome problems of targeting on irregular terrain, and can be more effective and cheaper on small and irregularly shaped areas.

[24]Bentley, Jay R., and Kenneth M. Estes. Effects of herbicide dosage rates on young pines. Manuscript in preparation, Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

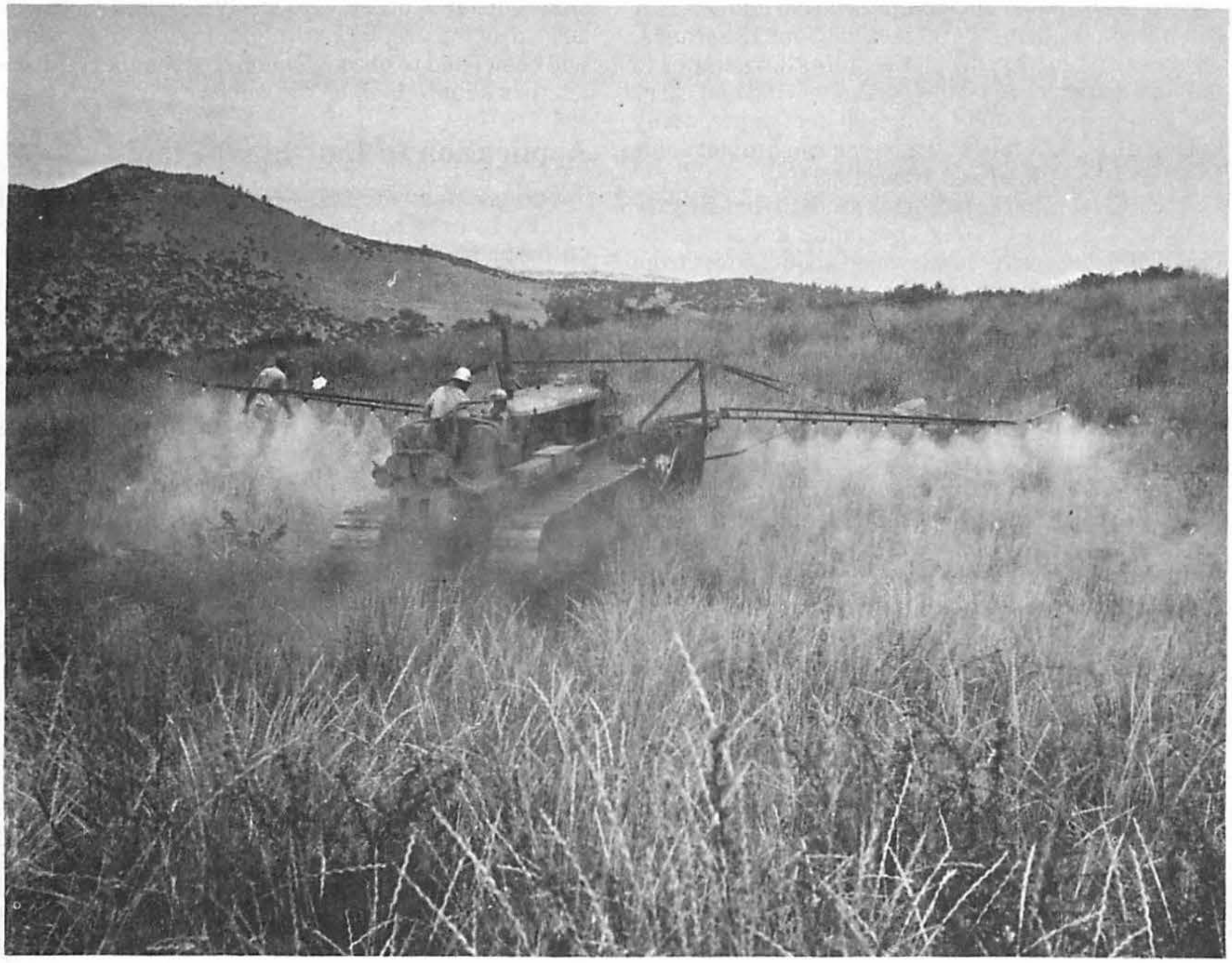

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Figure 29.—Tractor boom spraying may be more efficient than aerial spraying if terrain is gentle and relatively free of rock or brush obstructions. This method can be used even when fog or wind hampers aerial operations. In addition there is less drift hazard, and brush sprouts are more apt to receive a lethal spray coverage.

Aerial application usually has three important aims: (1) spreading a minimum volume of material uniformly over an area, to keep costs and herbicide use at a minimum; (2) covering leaf surfaces uniformly with small droplets; and (3) targeting the material within each swath, with minimum drift of material outside the target area. A gain in achievement of one of these aims usually means a loss in another.

Conventional spray emulsions ordinarily have been applied at volumes of 5 to 10 gallons per acre. Although field tests have produced somewhat conflicting results without definitely showing which volume is most effective the 10-gallon volume generally has been used in aerial spraying on California wildlands. Lower or higher volumes have been used for specific purposes.

The most desirable leaf coverage with conventional emulsions was achieved with about 72 droplets per square inch, and droplet spacing of 3.1 mm. Droplet spacing was more important than droplet size (Behrens 1957). Spray systems used in applying conventional emulsions are designed to produce about half of the droplets in sizes greater than 200 microns; this distribution theoretically gives a desirable leaf coverage under atmospheric conditions prescribed for spraying. Some 7.5 percent of the spray emulsion volume may be in smaller droplets (Hoffman and Haas 1969), which are subject to high evaporative loss and drift far outside of the swath. A water droplet 200 microns in diameter (1/5 mm or 1/125 inch)—the droplet size in heavy mist or very light drizzle—evaporates in 56 seconds, and a 50-micron droplet in only 3.5 seconds, in a hot atmosphere of 86° F and 50 percent relative humidity. A 200-micron droplet falls 50 feet in about 13 seconds, whereas a 50-micron droplet requires 3.4 minutes to fall this distance. A 3-mile per hour wind can carry the 200-micron droplet some 90 feet horizontally during its 50-foot fall, and a 50-micron droplet some 1,000 feet (Hoffman and Haas 1969).

During a southern California study, when a fairly constant wind of 1 to 4 miles per hour blew across the flight line, and spray was dropped about 25 feet from the helicopter, the measurable spray coverage at 80 feet downwind from the swath centerline was about half that in the swath directly under the helicopter, and a light herbicide effect was noted on shrubs 200 feet downwind (Plumb and others 1966). The herbicide drift did not severely damage the typical native vegetation, but would have been very undesirable if highly susceptible plants were nearby.

To keep drift within tolerable bounds, the aerial spraying is done when wind is under 5 miles per hour. Evaporative losses are reduced if the air temperature is below 70° F, and the operation should be stopped when the air temperature reaches 80° F. Similarly, a humidity greater than 40 percent is desirable.

A higher proportion of the spray material has been targeted within a narrow swath, with production of fewer small droplets, when the herbicide emulsions were thickened. Some were applied as "invert emulsions"—oil around the water phase—which have a consistency similar to mayonnaise. These required special equipment and great care in mixing and handling. Other emulsions were thickened by adding water-insoluble polymers (such as Norbak, Vistik, and Dacagen). They can be mixed thinner than inverts, and can be sprayed with conventional boom and nozzles. Foam-producing agents have been developed more recently as additives for reduction of herbicide drift.

The thickened emulsions fall as large drops irregularly spaced through the swath, so that leaf coverage is much less uniform than that of standard emulsions. Even so, the thicker emulsions have been used with success in controlling brush. In some situations, they have been stipulated for use in aerial applications as a means of limiting the hazard from herbicide drift. The thickened sprays only reduce the release of small droplets which drift readily—they do not eliminate it (Butler 1967). Extreme care in spraying is still required wherever sensitive vegetation can be damaged.

Another type of spray system, available commercially as the Microfoil boom of the Amchem Corporation, shows great promise for more uniform coverage with minimum drift problems. Droplets released at near zero pressure at the orifice are of constant size in the 800 to 1,000 micron range, producing as close to total drift control as is presently possible (Akesson and others 1971). With this relatively large droplet size, larger volumes per acre probably will be needed to obtain the desired number of droplets per square inch of leaf surface.

Application to Individual Plants

Foliage-stem sprays.—Spray material may be applied by hand to the leaves and small stems, or the entire plant, to the point of saturation coverage (fig. 30). Although lower concentration of herbicide is used in the spray emulsion, each plant receives much more herbicide than from broadcast spraying. Consequently, well-established brush regrowth is more apt to be killed, and resistant species better controlled. Hand spraying is most effective at the same season of the year recommended for broadcast spraying, but can be done earlier and later (Plumb 1963). Some brush species can be readily killed at most times of year after the leaves are fully formed.

Even though the initial hand spray penetrates better into dense shrub crowns and more plants are killed than by a single low-volume broadcast spray, repeat applications usually are needed for both methods (Gratkowski 1968; Plumb 1962a, 1962b, 1968; Green and others 1966). Translocation of herbicide to the root crowns in many brush species is limited regardless of application method; resprouting occurs on many if not all plants of resistant species. These plants can be killed by repeat sprays. Repeated hand spraying is needed also because some large brush plants are missed or incompletely covered during each operation, even on the most carefully supervised jobs, and many small seedlings are missed.

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Figure 30.–If broadcast spray treatments successfully remove most sprouting shrubs, the remainder, up to a few hundred per acre, can be eliminated with the more effective hand spray treatments.

One comprehensive test compared results from applications with hand-held hoses and wands and with a long broadcast boom—all mounted on tractor-drawn power sprayers. Three applications on young brush regrowth in consecutive years showed better control by broadcast spraying because of the better coverage of new seedlings.[25] Under most conditions, however, the seedlings are eventually killed if hand spraying is repeated for several years.

The usual hand spray mixture for control of brush on California wildlands includes 4 pounds a.e. of phenoxy herbicide, and a gallon of diesel oil in 100 gallons total emulsion. More concentrated mixture—8 or more pounds per 100 gallons, may be used in backpack sprayers if limited amounts will be applied on each plant (Plumb 1963). For herbicides other than the phenoxys, different concentrations may be used as determined by field tests.

The major limitations on hand spraying of individual plants are the slow progress and the high costs. Costs per acre vary widely because of differences in size of plants and numbers per acre, and because of variations in ease of access and walking over an area. Spraying of a brush plant 1 to 2 feet tall requires 15 to 20 seconds, whereas about 2.5 minutes are required if the plant is near 5 feet tall. Amount of herbicide needed for coverage is proportional to the time required for spraying. For sprouting plants ½ to 2 feet tall, total cost of hand spraying could be $22 to $25 per acre if distance between plants averages 12 feet—300 plants per acre. But costs are estimated to be $75 to $80 per acre if plants are spaced at 6 feet—1,200 per acre (Green and others 1963).

Hand spraying as the only herbicide treatment is limited to small areas where broadcast spraying is not feasible. Hand spraying can be used on large areas, however, in controlling brush stands already thinned by broadcast spraying. Even though relatively expensive, a combination of broadcast spraying with a hand-held boom, followed by foliage-stem spraying of the surviving plants, is particularly well suited to areas not easily sprayed by aircraft, such as timbered or wooded fuelbreaks, particularly along scenic roadways, and spots on rough terrain. The hand application methods also can be most effectively used in selective coverage of brush species to favor growth of valuable browse species, landscaping plants, or commercial forest trees.

Basal stem applications.—A variation in hand spraying of individual plants is spraying of only the basal stems rather than the foliage. This treatment is ordinarily used only on scattered large shrubs with tall, heavy crowns not easily sprayed, or on clumps of tall sprouts around tree or shrub stumps. The method is most effective on stems less than 3 or 4 inches in diameter. All of the bark is covered from below ground surface to a height of 12 to 14 inches. A mixture of 2,4-D and 2,4,5-T, or 2,4,5-T alone, is combined with diesel oil at 16 pounds a.e. per 100 gallons. The treatment is effective on both dormant and actively growing plants, but appears to be most effective if applied during active growth in the spring.

On larger stems, the herbicide is not sprayed, but is instead inserted through the bark into the cambium, by means of horizontal cuts, or frills, through the bark and cambium. The frills form cups into which a small amount of herbicide can be applied from a pump oil can. Specially designed injectors, which make the cut and insert the herbicide in one operation, may also be used. For hard-to-kill species, such as oaks, the frills must overlap to make an almost complete girdle around the tree. Undiluted 2,4-D amine or 2,4,5-T are effective herbicides (Leonard and Harvey 1965). Ammate at about ½ ounce of crystals per frill also can be used. Cacodylic acid, effectively used on hardwoods in Michigan (Day 1965), has produced erratic results in mixed conifer stands in northern California (Oliver 1970). The stem injection treatments can be made at any season, but best results usually are obtained from winter or spring applications.

Another individual plant treatment is spraying or painting of short, freshly cut stumps of trees and shrubs. Both the top and sides of the stump should be covered, and results are improved if 3 or 4 inches of the bud zone below the soil line are exposed and thoroughly wetted. The treatments should be applied as quickly as possible after cutting. Undiluted 2,4-D amine painted on the surface has been somewhat more effective than other herbicides in our tests, but results have been erratic in all treatments. A 1:1 brushkiller mixture of 2,4-D and 2,4,5-T at 8 to 16 pounds a.e. in 100 gallons of diesel oil, and ammate at 4 pounds per gallon of water, have both been effective. Applications in late fall, winter, or spring have produced varying degrees of control of resistant species, whereas late summer has been the poorest season for stump treatment. Followup foliage-stem sprays are always needed after the initial treatment of stumps.

Costs of the different stem and stump treatments are slightly higher than those of foliage-stem sprays. The various hand applications on individual plants are limited to situations where the brush control by broadcast foliage sprays is not feasible.

[25]Bentley, Jay R., and Kenneth M. Estes. A test of repeated herbicide applications for controlling regrowth of brush on pine plantations in northern California. Manuscript in preparation, Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Application to the Soil Surface

Herbicides in pellet or powder form can be used effectively for plant control when applied on the soil surface. Precipitation carries the herbicide into the soil and it enters the plants through the root systems for translocation into growing points. Soil application for management of fuels on wildland areas has been aimed at either control of brush regrowth, elimination of herbaceous fuel on firebreaks, or selected removal of annual grasses.

Soil applications to control brush.—Hand spreading of herbicides on the soil has been tested mainly for control of individual plants of sprouting brush. Limited tests have been made by hand broadcasting of pellets to control all brush plants.

For *individual plant applications*, three pelleted herbicides—picloram, fenuron (1,1-dimethyl-3-phenylurea), and karbutilate (Tandex—tert-butylcarbamic acid ester with 3-(m-hydroxyphenyl)-1,1-dimethylurea)—have been especially promising in tests (fig. 31). Unfortunately, demand has not been sufficiently great to keep them all in production. Fenuron is no longer available, and manufacturer representatives report that when current supplies of karbutilate are used up, it will probably not be restocked.

Fenuron granules applied by hand around scrub oaks, on the area formerly covered by the crown, did not affect the sprouting plants during the first season but produced maximum effects by the end of the third year. Our tests with material containing 25 percent active ingredient (a.i.) showed 17 to 50 percent kill for a rate of 0.8 ounce per plant, 40 to 100 percent kill for 1.6 ounces, and 83 to 100 percent kill for 3.2 ounces at different locations. Higher rates did not increase the kill of scrub oak. At the tested rates, fenuron killed 70 to 90 percent of chamise plants, up to 100 percent in one case, and 95 to 100 percent of hoaryleaf ceanothus (*Ceanothus crassifolius* Torr.).

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Figure 31.–Picloram and karbutilate effectively killed red shank, as shown here, when applied at low rates to the soil around sprouting brush. Sage and ceanothus were also killed, but scrub oak required heavier rates, and was not always killed at any rate tested.

Picloram pellets, at 10 percent a.e. produced only slight leaf damage at ¼ ounce per scrub oak plant, 7 to 15 percent plant kill after 2 years at ½ ounce, 30 to 40 percent at 1 ounce, and up to 60 percent at 1½ ounces. At the low rate of ¼ ounce per plant, picloram killed 40 to 60 percent of sprouting chamise, 80 percent of red shank plants, and 90 percent of hoaryleaf ceanothus; at ½ ounce per plant the kill of different species ranged from 80 to 90 percent, and at 1 ounce from 90 to 100 percent.

In another southern California test, plant kill with fenuron applied at 10, 20, and 30 pounds a.i. killed about 35 percent of scrub oak at the lower rate and 87 percent at the high rate. Picloram at 12 pounds a.e. killed 87 percent. Karbutilate at 8 pounds killed 71 percent of scrub oak and at 16 and 24 pounds, 100 percent. Final results were not achieved until 3 years had passed.

Similar results were obtained with fenuron and picloram applied on scrub live oak in Arizona (Davis and Pase 1969). Again, Agricultural Research Service scientists obtained 67 to 94 percent kill of honey mesquite (*Prosopis chilensis* (Molina) Stuntz.) in New Mexico trials with fenuron, their most effective herbicide (U.S. Department of Agriculture 1965).

Karbutilate and picloram pellets were applied around sprouting scrub oak plants on the Los Padres National Forest. Occasional plants were killed by ½ ounce of picloram over 2 to 3 years. One ounce per plant killed 33 percent, and 1½ ounces 63 percent. At 2 ounces per plant, karbutilate killed 10 percent, and at 4 ounces, 50 percent. Other shrub species were generally killed more readily than scrub oak. Thus, these herbicides can have a place in controlling brush plants not killed by foliar sprays. They allow some selective treatment to leave desirable woody vegetation on an area.

In *broadcast applications*, pelleted picloram in one southern California test, when broadcast at 5 pounds a.e. per acre (50 pounds of the commercial product) killed about 10 percent of the scrub oak plants, about 60 percent at a 10-pound rate, and over 70 percent at a 20-pound rate. Karbutilate at 16 and 24 pounds a.i. killed nearly all scrub oak plants.

When tested as a broadcast application in pellet form for desiccation of mature chaparral in both northern and southern California, picloram was highly effective at rates of 8 to 12 pounds a.e. per acre (Bentley and Graham 1976a). Effects were spotty at a 4-pound rate. The soil application produced greater kill of understory shrubs and generally a greater kill of all woody vegetation than obtained from broadcast foliar sprays. However, the phenoxy herbicides as foliar sprays were sufficiently effective in preparing the brush fuels for burning, and at a lower cost than the picloram pellets. The broadcast picloram was effective by the end of the first growing season when applied during either the preceding fall or winter. But applications made in the spring at the end of the rainy season were not effective until the second growing season.

The broadcast applications of herbicides to the soil have best possibilities, at this time, for controlling dense stands of hard-to-kill species, such as scrub oak.

Sterilants to control weeds.—Herbicides have been tested for eliminating all herbaceous fuel on narrow firebreaks, to avoid or reduce the annual cleaning by hand or mechanical operations. Use of herbicides may be cheaper, and will cause less soil disturbance, than other methods.

Tests were conducted in chaparral areas of southern California and mixed-conifer areas of northern California. The chemicals were applied at rates described as low, moderate, and high for each herbicide. Diuron proved to be the most effective sterilant for most locations, although monuron and bromacil (5-bromo-3-sec-butyl-6-methyluracil) were more effective on the driest sites (fig. 32). Bromacil was not effective by the second and third years after application where precipitation totaled about 60 inches per year. Fenac—(2,3,6-trichlorophenyl) acetic acid—eliminated broadleaf plants but left a nearly pure stand of annual grasses. Benzabor—a combination of borates and a benzoic acid compound—was the least effective sterilant and very large quantities were required.

F-523584

Figure 32.—Bromacil at 3.2 pounds a.i. per acre eliminated all annuals from this northern California sterilant plot, but did not kill the biennial hairy mullein (*Verbascum thapsus* L.), nor perennial grass. This "selective" plant control was later used to eliminate downy brome grass (*Bromus tectorum* L.) from fuelbreak sites in Utah and Idaho.

Monuron, diuron, and simazine, at rates from 12 to 48 pounds per acre, eliminated nearly all herbaceous plant growth during the first year at all locations, except under the highest precipitation. They were generally effective during the second and third years, with some decline by the third year, however, especially for lower application rates and highest precipitation areas.

These sterilants have relatively short-term effects; they need "booster" applications at intervals of 2 to 3 years on most sites, and yearly in areas of high precipitation.

Selective control of annual grass.—One method for improving the fuel characteristics of herbaceous vegetation is application of herbicides to eliminate the annual grasses, such as downy brome, in which fires spread rapidly during the dry season. The objective is to leave perennial grasses and summer-growing forbs, which are needed for soil protection and esthetic purposes, and do not present as hazardous fire control problems. Herbicides for this purpose were tested in Utah during 1967 to 1970.

When applied during the fall, both atrazine—at 1.2 and 2.4 pounds a.i. per acre, and bromacil, at 1.6 and 3.2 pounds, effectively eliminated downy brome. Simazine, at 1.2 and 2.4 pounds, was almost as effective. Diuron and monuron were less effective. Fenac removed forbs but not the grass. Although atrazine and simazine did not harm the native perennial sand dropseed grass (*Sporobolus cryptandrus* (Torr.) A. Gray.) and the annual forbs, bromacil killed these species. Two growing seasons after application, the atrazine maintained good control of downy brome. Monuron at a heavy rate still controlled the annual grass but damaged the perennial grass.

The most feasible treatment appeared to be application of atrazine at 2 pounds a.i. per acre on alternate years for sandy loam soil typical of much of the downy brome grass-sagebrush range east of the Sierra Nevada.[26]

Tests of this treatment were started on an operational scale in 1971 on 10 National Forests in the Intermountain Region. Strips 33 feet wide were

[26]Green, Lisle R., Robert L. Beschta, and Gene W. Benedict. Data on file at the For. Fire Lab., Riverside, Calif.

broadcast sprayed along truck trails, with a boomjet nozzle on a standard slip-on pumper in a pickup truck.

This approach to herbaceous fuel management appears promising for many parts of California where annual grasses produce undesirable fuels. Simazine, with a solubility of only 5 parts per million in water, would appear to be the safest herbicide for controlling herbaceous vegetation among desirable shrubs or trees. Atrazine, monuron, and diuron also are used at light rates, however, in California vineyards and orchards.

ESTABLISHING AND MAINTAINING GROUND COVERS

Vegetation-fuel management on California wildlands includes both the development of suitable vegetation cover and its maintenance indefinitely. Adequate ground covers on the extensive areas being modified to aid in fire control are required for soil protection and for esthetic purposes—a good ground cover is an essential feature of the total environment. Bare soil cannot be tolerated, except on narrow firelines or firebreaks. A new protective cover must be artificially established quickly after clearing operations which remove all of the vegetation at one time, the common procedure during construction of fuelbreaks in chaparral. The new ground covers may be naturally established on areas where excess woody vegetation is removed gradually as part of a thinning operation, such as the so-called light burning.

As part of a type-conversion process, establishment of a new cover is started soon after initial removal of woody material, before control of new brush regrowth has been completed. Maintenance operations, as part of longtime management, do not begin until the first surge of brush reinvasion has been brought under control—at least 3 years after initial brush removal.

Selection of the new ground cover is determined primarily by site productivity and by the future dominant land use, or uses—watershed, wildlife habitat, livestock range, commercial timberland, scenic landscape. The treatments used in establishing the new ground cover depend on the nature of the original woody cover, the method used to remove it, and the kind of new cover that is desired. Three broad classes of possible new covers are (1) annual-plant herbaceous ground covers, (2) perennial grass ground covers, and (3) low-volume shrubby ground covers. These may form part of an open savanna type, or may be under a discontinuous overstory canopy of woodland or conifer forest.

Annual-Plant Herbaceous Ground Covers

A ground cover of herbaceous plants, usually dominated by annual grasses, becomes established naturally after removal of woody vegetation. But the time required to develop a continuous cover of annual grasses depends largely on the density of the original woody canopy, the continuity of the original grass stand, the abundance of herbaceous plant seed, and the degree to which seed was destroyed during removal of the woody vegetation.

In the more open woody types, the herbaceous cover in the openings between trees or shrubs is similar to the grassland types occurring in the locality. In the foothills and lower mountains of California, the herbaceous cover is primarily made up of annual grasses and forbs, dominated by naturalized species, including *Bromus, Festuca, Avena, Erodium,* and many other plant genera. Native perennial grasses occur with the annuals in the mountains, particularly on the eastern slopes of the Sierra Nevada and Cascades, and lesser stands, or occasional plants, in the Sierra Nevada foothills and in the Coast ranges. Seed supplies are abundant each year after maturity of the annual plants. This seed supply is not destroyed during removal of the woody vegetation by hand or mechanical clearing, or by broadcast burning, except in small spots where trees or shrubs were uprooted or burned. A relatively continuous cover of annual grasses and forbs becomes established during the first year after removal of woody vegetation.

In semidense woody vegetation, the stand of herbaceous plants is spotty, being fairly dense in the small openings between woody plant crowns and thin or absent under the crowns. Annual grasses are more numerous than forbs, particularly in semidense chaparral of low stature. The herbaceous plants—suppressed by the woody vegetation—produce a fairly continuous seed supply, but it is much less abundant than in more open woody types. Even so, a relatively continuous grass stand develops during the first year after brush removal by disking (Bentley 1967). Bulldozing leaves a more irregular supply of seed, and a spotty grass cover develops during the first year. Broadcast burning with a hot fire destroys much of the grass seed; a spotty grass stand occurs during the first year, but this usually develops into a relatively continuous cover by the second year. After either bulldozing or broadcast burning, sowing of grass seed often is undertaken in an attempt to speed development of a continuous protective soil cover.

Under a dense cover of woody vegetation, the stand of herbaceous plants is very sparse. The few plants of annual grass, with their supply of viable seed, are widely scattered. Natural regeneration of herbaceous cover during the first year is limited almost entirely to a thin stand of forbs. After burning of dense chaparral, the first plants are annual forbs described as genetically pre-adapted to the fluctuating environmental conditions in chaparral subject to periodic burning (Sweeney 1956). In other words, they grow only during the first year or two after a fire and the seed lies dormant under the developing chaparral cover until it is once again removed by fire. For example, after a hot wildfire burned a 40-year-old stand of dense chaparral in the San Gabriel Mountains, the first year herbaceous cover was a fairly uniform stand of *Emmenanthe pendulifera* and species of *Phacelia, Mentzelia, Mimulus,* and other broadleaved plants which had been uncommon or rare under the chaparral before burning. Annual grasses were absent the first year, except in spots where the chaparral had been fairly open before burning. The vigorous grass plants produced abundant seed each year until they became dominant in the herbaceous cover by the fourth year after burning. By this time, however, the brush regrowth was replacing the herbaceous vegetation, except where brush had been controlled by herbicide treatment.

After removal of dense woody vegetation in California, sowing of grass or other herbaceous plants definitely is needed to establish a continuous protective soil cover by the end of the first year after brush removal. Annual ryegrass has been sown as an emergency treatment to provide temporary soil protection after wildfire burning on many thousands of acres of watershed in California (California Division of Forestry 1974). After this emergency treatment on many large areas, no additional attempt is made to alter the natural plant succession towards development of a dense brush cover. On fuelbreak areas, however, where brush regrowth is held in check by herbicide spraying or other treatment, annual grasses may be sown to add some soil cover during the first few years after clearing, while a natural grass-forb cover becomes established. The sown grass also adds extra fuel that is helpful if prescribed burning is planned as a brush control treatment.

Annual Grasses for Emergency Sowing

Common or Italian ryegrass *(Lolium multiflorum* Lam.) is the most commonly sown annual grass. It is a winter-growing species with strong seedling vigor, and it responds better than most annual species to the increased soil nutrients present after a hot fire in dense brush. Seed supplies are abundant and cost has been low (for many years about 10 cents per pound, but about 40 cents in 1974). Although the plants grow slowly during the winter, a successfully established stand provides good soil protection by early spring, and the deep roots compete heavily with brush seedlings at the end of the rainy season. The heavy seed crop produces a dense grass stand during the second year. After the second or third year, as soil nutrient supply is lowered and other annual species have increased greatly, the ryegrass declines and drops out of the stand, except for occasional plants. A mixture of grasses and forbs natural to the site gradually develops as the longtime herbaceous cover. Its species composition depends on site productivity, degree of livestock grazing, and use of fire or other brush control treatment.

Another annual ryegrass—Wimmera *62* (*L. rigidum*)—has grown better than the common variety on drier sites having less than 15 inches annual precipitation. Wimmera *62* is particularly well adapted in southern California under a short rainfall season. It flowers early and matures seed about 2 weeks ahead of common ryegrass (Edmunson and Cornelius 1961). Seed of Wimmera *62* is consistently larger, a factor related to greater seedling vigor (Whalley, McKell, and Green 1966). It is the best short-lived annual grass for quick erosion control (Miller 1962). Seed supplies are more limited and the price is slightly higher than for common ryegrass, but the cost is justified where rainfall is low and limited to a short season.

Blando brome (*Bromus mollis* L.) is the best of the naturalized annual grasses for herbage production on California foothill ranges. It is widely adapted, but is least abundant on low rainfall areas and coarse sandy loam soils, particularly in southern California. It has consistently produced good stands from broadcast sowing in northern California—better than ryegrass on poor seedbeds. But blando brome has not been so widely sown as ryegrass; mainly because the seed supply is more limited and costs are higher. An important reason for sowing blando brome at a low rate, in mixture with other grasses, is to establish a stand that will remain as part of the longtime natural herbaceous cover. If seeded alone, blando brome does not provide as much early soil protection as ryegrass, assuming equal success in stand establishment.

Seedbeds.—Annual grasses usually are broadcast sown, commonly by aircraft, as a relatively low-cost application. The seed is seldom covered by means of mechanical equipment, such as a chain, drag, or spiked roller drawn behind a heavy tractor, but stands are always better if seed somehow is covered with soil. Success ordinarily depends on the seedbed conditions at the time of sowing, but is influenced by weather during the fall and winter. The best seedbeds have a mellow soil surface within which the seeds are covered by the first fall rains. New seedlings from well-covered seed develop better root systems and are less affected by dry, hot, or cold weather than are seedlings from uncovered seed. Most failures from broadcast seed can be attributed to mortality of seedlings perched on top of a hard soil surface.

Sowing is most needed and most consistently successful following a hot fire in mature dense chaparral (fig. 33). Consumption of the ground litter leaves a mellow soil surface covered by a film of white ash immediately after the fire, with spots of deeper ash where heavy woody material has been consumed (Bentley 1967). Mechanical covering of the seed usually is not essential, although it will insure greater success in the years with dry, cold weather during fall and winter.

Sowing is badly needed but seldom fully successful following a hot fire in dense chaparral where litter on the soil was scarce—as it commonly is on sites with poor soil. Ash from burned woody material disappears rapidly, leaving a bare, hard soil surface. Broadcast sowing on these sites seldom produces satisfactory grass stands, but in trials, covering of the seed has consistently produced good stands of ryegrass. On poor seedbeds, covering is advisable wherever annual grass is sown for temporary soil cover on fuelbreak areas.

Sowing also is needed where dense brush has been removed by bulldozing that has disturbed most of the soil surface, but results from uncovered seed have been variable. Covering of the seed is needed

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Figure 33.—A successful stand of annual grass, as shown here, requires loose soil or ash seedbed, seeding ahead of winter rains, and periodic rainfall during late winter and spring. Frequently the stand thickens the second year following seeding.

on spots where the blade has left a hard soil surface, but grass stands become established on spots with a mellow soil surface, and in depressions. Disking generally leaves a seedbed satisfactory for broadcast sowing. However, the most consistent success is obtained from covering of seed on all areas cleared by mechanical equipment.

Hand clearing usually leaves sufficient seed and litter for covering the seed, and hand-cleared areas are seldom sown; the litter alone is usually depended on for soil protection until a natural herbaceous cover becomes established.

Sowing is less needed after removal of semidense woody vegetation, as compared to dense types, and success from sowing is intermediate. The temporary grass cover is needed only on spots where the litter layer and woody plants have been removed by burning or mechanical treatment. If these spots make up at least half of the total area, the sowing of temporary annual grasses probably is advisable, and seedbed conditions on these spots determine the success of the treatment. The remainder of the area develops a natural grass-forb cover.

Grass sowing is seldom needed, and seedbed conditions usually are unsatisfactory, where thin stands of brush interspersed with grass have been removed by burning. These seedbeds can be recognized by the so-called "black ash" condition after burning, caused by the presence of charred brush stems and grass stubble. Heat from the fire has seldom been sufficiently intense to destroy all of the herbaceous plant seed near the soil surface (Bentley and Fenner 1958).

Sowing rates.—The objective in sowing annual grasses is to establish a fairly continuous stand the first year, which will develop into a dense cover by the second year. Numerous trials, started in 1949 on burned woodland and chaparral sites, showed that approximately 10 pounds per acre of ryegrass seed produced satisfactory stands on suitable seedbeds; the stands were more uniformly continuous than from a 5-pound rate.[27] A 15-pound rate produced heavier first-year crops of ryegrass on favorable sites than did 10 pounds, but little was added by sowing at a 30-pound rate; the second-year stands were sufficiently uniform from rates of 10 to 30 pounds. However, on bare, hard seedbeds in burned chaparral, the ryegrass stands were poor, or failures, from all rates of 5 to 30 pounds per acre, unless the seed had been mechanically covered. Shultz and Biswell (1953) found that first-year foliar density of ryegrass in April, from sowing in a good seedbed on a productive woodland site, was much lower from a 3-pound sowing rate than from a 5-pound rate, and it was little increased by a 9- or 12-pound rate.

[27] Bentley, Jay R. 1949–1963. Data on file at the Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Ryegrass commonly is aerially applied at about 8 pounds per acre; this method produces adequate stands on good seedbeds or where the seed is covered by dragging a chain or other equipment across the soil surface after sowing. At 1974 prices, the cost of seed would be approximately $3.20 per acre for common ryegrass. Helicopter application costs are about $1.00 to $2.00 per acre, plus cost of transport to the site, which may average about $0.75 per acre for small jobs. Labor, mileage, and supervision cost about $1.50 per acre, making a total of about $6.00 to $7.00 per acre for broadcast sowing.

Maintenance of Natural Annual Covers

A natural herbaceous cover of annual grasses and forbs can be maintained, if desired, as a protective soil cover on wildland areas where hazardous woody material has been removed. The aggressive annual plants characteristic of California grasslands take over and dominate the cover on most sites, even though other annual grasses have been sown to provide temporary soil protection. On some mountain sites the natural cover becomes dominated by native bunchgrasses mixed with annuals.

If reinvasion by woody plants is kept under control, a natural herbaceous cover persists, and generally provides adequate soil protection. Possible exceptions include some unstable steep slopes with greater than 80 percent gradient where studies indicate that deeper-rooted woody plants are needed to reduce soil slippage (Rice and others 1969; Rice and Foggin 1971). The natural herbaceous cover is relatively stable under most California site conditions; abundant seed supplies are always present, a dense stand of new plants establishes itself each year after the fall rains, and the new vegetative growth and old litter protect the soil during the winter rains, provided the area is not heavily grazed and trampled by livestock or wildlife.

The natural cover is least stable on droughty soils, particularly under low average rainfall in southern California, where semiwoody plants tend to replace the herbaceous cover. Establishment of superior new plant covers is most difficult on such sites. At present, the only feasible procedure on these sites appears to be a rather constant maintenance effort, as required to hold a natural vegetation cover satisfactory for fire control.

A dense natural cover of annual plants, or perennial grasses and annuals in the mountains, extracts available moisture from the upper soil as the plants mature in late spring or summer. This reduces the possibility for survival of any new woody plant seedlings which may come from seed germinating after the initial surge of invading brush plants has been eradicated. A few brush seedlings may become established in openings within the herbaceous cover. In years of heavy spring rainfall, many brush seedlings may survive because of favorable soil moisture into the summer. On droughty soils having a thin herbaceous cover, many seedlings of semiwoody plant species will survive in years of above-average winter and spring moisture.

Gradual reinvasion of new brush plants into natural herbaceous ground covers can be controlled with minimum maintenance effort. Browsing by wildlife or domestic stock may keep the brush plants to a small size for many years, or the excess plants can be easily eliminated by hand grubbing or herbicide applications. However, heavy reinvasion of brush in any one year will require quick action within 2 years. Broadcast treatment, by prescribed burning or herbicide spraying, and possible followup by hand treatment will be needed to bring the brush under control. Although a good natural cover of herbaceous plants aids in keeping brush reinvasion under control, constant vigilance will be necessary to make sure that natural plant succession towards a woody vegetation cover is kept within satisfactory limits.

A cover of low-growing forbs and grasses is preferred for easy fire control on fuelbreaks and other areas. Fire spreads rapidly in such cover after the annual plants have dried, but heat output is relatively low, fire behavior is predictable, and firebrands are not carried long distances. Such low vegetation can be burned out readily from clean firelines, or fires can be extinguished with retardants.

On productive sites, however, the low-growing vegetation is rapidly replaced by tall annual grasses, which present much greater difficulties in fire control. The natural succession to a tall annual grass subclimax is caused mainly by buildup of a litter cover, which produces conditions favorable for growth of seedlings of tall grasses, such as wild oats (*Avena* spp.) and ripgut brome (*Bromus rigidus* Roth.). Moderate grazing by livestock can prevent the litter build up and favor growth of a grass-forb mixture. On areas which will not be grazed by livestock the most practical means of reducing the litter is periodic burning. Prescribed fire can have the additional values of brush control and reduction of highly flammable fuel during the years of burning.

Suggestions for maintenance and management of fuelbreak areas are summarized in a later section.

Perennial-Grass Herbaceous Ground Covers

Perennial grasses are the plants most widely used on California wildlands to improve fuel and forage characteristics of the ground cover (fig. 34). Site adaptation of the grasses is fairly well known, seed supplies are plentiful and relatively low cost, and techniques have been developed for establishing the grasses on cleared brushland areas. Broadleaf plants which might be equal, or superior, to grasses in fuel characteristics cannot be so readily established. Also, perennial grasses have deep fibrous root systems and fairly stable production year by year, so that they are valuable for soil protection and for competing with young brush plants—an important aid in maintaining the cover on fuelbreaks. The perennial grasses are palatable to livestock and some wildlife, and can be kept to low stature through grazing pressure.

Perennial grasses also produce less hazardous fuel than does the natural herbaceous cover on most California wildlands where protection from wildfire is a critical problem (fig. 35). The deep-rooted perennials stay green later into the summer than do annuals. For example, in a Great Basin vegetation type, moisture content of sand dropseed was 50 percent, or greater, during July and August when that of annual downy brome grass was below 10 percent.

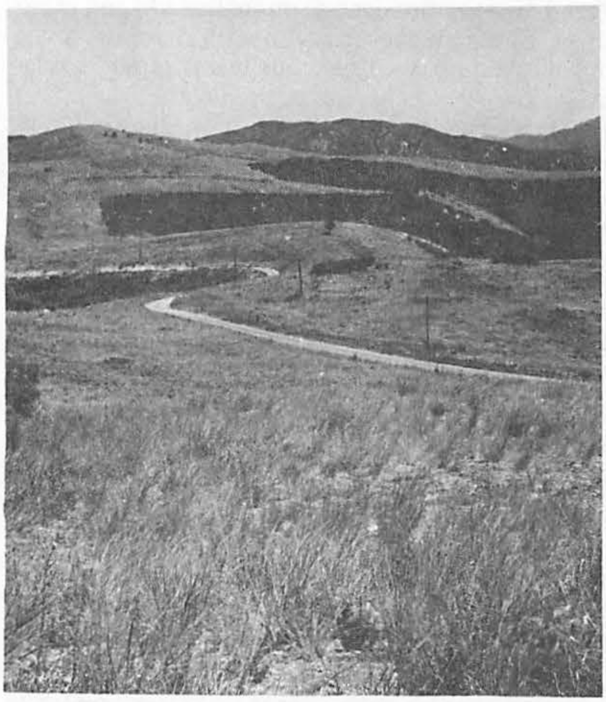

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Figure 34.—Perennial grasses are favored over annuals for fuelbreaks. With suitable soil and rainfall, they occupy the site for many years, supply forage for grazing animals, and provide a good location for fire control.

Mixtures of perennials with highly flammable annuals—the common herbaceous cover developed from sowing perennials at lower elevations in California—should have lower heat output during burning than annuals alone. In the mountains and on the east side of the Sierra Nevada and Cascades, a full stand of perennial grasses can hold down growth of the more flammable annuals and produce a ground cover with favorable fuel characteristics.

The most critical step—the one in which consistent success is most difficult to attain during the type conversion process—is establishment of a satisfactory grass stand before competition from natural annual plants becomes excessive. This step requires choice of a suitable site, selection of adapted perennial grass species, preparation of a clean seedbed, and proper sowing of the seed—to assure the best possible stand during the first critical year after sowing. A second important step, usually started during the first year, is full control of vigorous sprouting brush, which can eliminate the perennial grasses if left uncontrolled for 2 or 3 years (Bentley 1967).

Choice of Site

Sites most promising for perennial grass production have soils similar to those supporting natural grassland or grass-woodland vegetation.

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Figure 35.—No plant cover on fuelbreaks is wholly acceptable to firefighters, but perennial grass can serve as fuel to start a backfire or burnout.

Suitability of a site can be judged by texture, depth, and stoniness of the soil, which determine the water-holding capacity of the upper soil levels (Bentley 1967). A water storage capacity of 3 to 4 inches, or more, in the upper 3 feet—with precipitation adequate to fill this capacity during most of the rainy period—is needed for stable perennial grass production. Soils with a capacity of 2 to 3 inches are borderline. Loams, silt loams, and clay loams can store about 2 inches of water available to plants per foot of soil depth; sandy loam about 1.5 inches (U.S. Department of Agriculture 1955). Shallow sandy loams are poor sites for perennial grasses, especially if yearly rainfall is not dependable or occurs during a short season, as in southern California. On sites with soils of less than 2-inch storage capacity, the best course is to establish an annual grass-forb ground cover rather than sow perennial grasses.

The most consistent success from sowing perennial grasses in the California foothills has been on sites having clay loam or clay subsoils with adequate water storage capacity. In general, a medium-to-fine-textured soil should be about 2 feet deep and a sandy loam nearly 3 feet deep, for adequate water storage. If stony, the soils should be deeper.

In the California foothills and lower mountains where the hot, dry season extends for about 5 months, or longer, at least 20 inches average annual precipitation is needed for stable perennial grass production. Where air temperature and relative humidity are moderated by coastal influences, the requirement is near 15 inches. In all locations having borderline minimum precipitation, the perennials grow better on east- or north-facing slopes than on the more droughty exposures, which also usually have shallower soils. Where precipitation is less than 15 to 20 inches, again the best course is to establish annual grass-forb ground covers.

In the mountains where summers are shorter than at lower elevations, a minimum of 10 to 15 inches average annual precipitation is needed for perennial grass production. Precipitation is well above this level on most mountain sites, except on the east side of the Sierra Nevada and Cascades. On the desert side of the mountains in southern California, where climate is unfavorable for both annuals and perennials, the perennials are sown if average precipitation is greater than 15 inches.

Selection of Species

Only a few of the introduced perennial grass species have proved well adapted for establishing full stands which will persist for many years on cleared brushlands in California. By the early 1950's, after many seeding trials in the foothills, hardinggrass (*Phalaris tuberosa* var. *stenoptera* (Hack.) Hitchc.) had proved superior as a long-lived perennial in the brushland zone having mild to cool winters, and was recommended as the base species for sowing in this zone (Bentley and others 1956). Later trials showed that intermediate wheatgrass (*Agropyron intermedium* (Host) Beauv.) and pubescent wheatgrass (*A. trichophorum* (Link) Richt.) could be grown successfully in brushland zones not favorable for hardinggrass, especially in the mountains of southern California (Green and others 1963). These wheatgrasses had been used for years on cleared land on the east side of the Sierra Nevada and Cascades (Cornelius and Talbot 1955). Crested wheatgrass (*A. cristatum* (L.) Gaertn.) has been commonly used on the sites exposed to desert influences.

Other perennial grass species have been recommended as alternates to the basic hardinggrass or wheatgrass species, partly because of lower costs. In early sowings several species were used in mixture, sometimes with no one species in amounts sufficient to produce a full stand. The purpose in most cases was to establish a grass stand quickly—in part a defensive measure against criticisms that brush removal presented a high erosion hazard. The aggressive annual ryegrass sometimes was added to the mixtures, even though it obviously added excessive competition with the slower growing perennials. Some of the alternate species can still be sown in mixture with the basic perennials, as shown in the list of different usable mixtures (table 2).

The annual blando brome is recommended for sowing in mixture with perennials on foothill sites at a rate no greater than ½ pound per acre. At this rate it is not competitive with perennial grass seedlings during the first year of establishment. The blando brome fills in the spaces between the perennial plants during the second year, reducing the otherwise inevitable encroachment of less desirable annuals. However, if the seedbed for perennials already contains a supply of annual grass seed, the blando brome will only add extra first-year competition; *it should be omitted* from the mixture. Aggressive ryegrass *should never be added* to the perennial grass mixture.

The upper elevational limit of the so-called "Foothill Zone" (table 2), where hardinggrass is best adapted, has not been well defined. It actually extends in some localities into the conifer zone of the lower mountains where snow and freezing temperatures occur for short periods in most years. This upper level varies from below 3,000 feet in northern California up to 4,000 feet in southern California. Similarly, the lower limits of the "Mountain Zone," where wheatgrasses are the basic perennials, are

TABLE 2.—*Choices of perennial grass mixtures for soils of adequate water storage capacity in the foothill and mountain zones of California* [1]

Zone and grass species	Sowing rate [2]						
	Lowest ←			Rainfall range			→ Highest
	Mixture 1	Mixture 2	Mixture 3	Mixture 4	Mixture 5	Mixture 6	Mixture 7
				Pounds/acre			
Foothill zone:							
Hardinggrass (*Phalaris tuberosa stenoptera*)	3	2	2	2	2	2	2
Intermediate wheatgrass (*Agropyron intermedium*)					1	2	2
Pubescent wheatgrass (*Agropyron trichophorum*)		3		2	2		
Tall wheatgrass (*Agropyron elongatum*)				2			
Smilograss (*Oryzopsis miliacea*)			1		1		
Veldtgrass (*Ehrharta calycina*)			2				
Sherman big bluegrass (*Poa ampla*)						1	
Tall fescue (*Festuca arundinacea*)							2
Annual blando brome (*Bromus mollis*)	½	½	½	½	½	½	½
	Mixture 8	Mixture 9	Mixture 10	Mixture 11	Mixture 12	Mixture 13	Mixture 14
Mountain zone:							
Crested wheatgrass (*Agropyron cristatum*)	5	3					
Intermediate wheatgrass (*Agropyron intermedium*)			3	2	2	2	4
Pubescent wheatgrass (*Agropyron trichophorum*)		2	3	2			
Tall wheatgrass (*Agropyron elongatum*)				2			
Tall fescue (*Festuca arundinacea*)					2		
Orchardgrass (*Dactylis glomerata*)					2		
Smooth brome (*Bromus inermis*)						3	
Timothy (*Phleum pratense*)						1	
Sherman big bluegrass (*Poa ampla*)							1

[1] Planting sites in the foothill zone of the Central Valley, Coast Ranges, and southern California should have minimum average annual precipitation of 20 inches inland, and 15 inches under coastal influence. The elevation roughly separating the foothill from the mountain zone is 3,000 feet in northern California, and 4,000 feet in southern California.

[2] Rates given are for drill sowing; increase up to double for broadcast sowing.

not well defined. This zone may drop down to 3,000 feet in parts of southern California influenced by cold, dry winter winds.

Some of the most commonly sown perennial grass species are described here.

Hardinggrass grows slowly the first year but in time develops large deep-rooted clumps which persist well under grazing pressure. It grows vigorously for a few years on many burned-over brushland sites, but commonly the vigor declines after the initial soil fertility level is reduced. Legumes, or possibly fertilization, are needed to maintain desirable herbage production. Hardinggrass is highly palatable and will be grazed closely on livestock range. It is a winter grower and provides good soil protection where winters are not severe. This species can be sown as the only perennial grass on the better foothill sites (mixture 1, table 2), but pubescent wheatgrass or other species usually are added on less productive sites, particularly in the upper foothills where wheatgrasses are well adapted. Whether it is used alone or in combination, sufficient hardinggrass seed should always be sown to produce at least a fairly uniform stand.

Intermediate and *pubescent wheatgrasses* have vigorous first-year seedlings, which later spread by short rhizomes to form large bunches or loose sods (fig. 36). They persist well on soils of fair-to-good fertility levels. They provide excellent protective ground covers on fuelbreak areas. Under proper grazing management on mountain sites, they can occupy the site to virtual exclusion of highly flammable annual grasses. Pubescent is better adapted on dry areas and intermediate on the more productive sites. They commonly are sown together with a preponderance of pubescent on the drier sites. Singly or together these two species are part of most mixtures on mountain or foothill sites (table 2).

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Figure 36.—Intermediate and pubescent wheatgrasses (foreground) have a built-in advantage in the competition for space on fuelbreak sites because they reproduce and spread from short rhizomes. Bunchgrasses, such as crested wheatgrass (upper right) must spread from seed, and do not generally do so except where drilled in prepared seedbeds.

Crested wheatgrass is a small bunchgrass well suited as fuelbreak cover on dry sites, particularly where it grows in stands dense enough to suppress downy brome or other aggressive annuals. It is sown in the Mountain Zone near desert areas. Often it is sown alone but can be combined with pubescent wheatgrass (mixtures 8 and 9, table 2).

Tall wheatgrass (*Agropyron elongatum* (Host) Beauv.) is a large coarse bunchgrass having strong seedling vigor. It has established itself and grown well on fuelbreak areas in the upper foothills and lower mountains in southern California. It can make up part of the wheatgrass mixture (mixture 4) where its large plants are not objectionable or where it is grazed down by cattle.

Smilograss (*Oryzopsis miliacea* (L.) Benth.) is a bunchgrass which persists well on lower foothill sites. Formerly it was included as a basic perennial grass in the Foothill Zone (Bentley and others 1956), but we list it as an alternate species because of the difficulty in establishing good stands by drilling. Soaking the seed in full strength chlorine bleach for an hour or in 70 percent sulfuric acid (Koller and Negbi 1959) increases germination and may add to success in sowing this species. It can be added at 1 pound per acre to hardinggrass (mixtures 3 and 5).

Veldtgrass (*Ehrharta calycina* Sm.) can be added to hardinggrass on coastal sites and in southern California (mixture 3). At the San Dimas Experimental Forest, it grew well to 4,000 feet elevation.

Goars tall fescue (*Festuca arundinacea* Schreb.) does not persist well at low elevations but is an alternate species for sowing in the upper foothills and mountains of the Sierra Nevada and North Coast Ranges where annual precipitation is more than 30 inches (mixtures 7, 12).

Orchardgrass (*Dactylis glomerata* L.) is an alternate species for the mountains of the Sierra Nevada and North Coast Ranges. It can be added at 1 or 2 pounds per acre to mixture 12.

Smooth brome (*Bromus inermis* Leyss.) is a highly palatable sod-forming grass adapted on mountain sites in northern California. It has proven valuable for sowing on burned-over pine forest sites in northeastern California (mixture 13).

Timothy (*Phleum pratense* L.) can be added at 1 pound per acre to mixture 13 on moist sites.

Sherman big bluegrass (*Poa ampla* Merr.) is a bunchgrass that provides early cover on fuelbreak sites. It can be sown on foothill or mountain sites (mixtures 6 and 14).

Seedbed Preparation

First-year seedlings of perennial grasses grow slowly and do not compete strongly for moisture in the upper soil, as compared to the more aggressive natural annuals or ryegrass, which extract moisture rapidly during the spring months at the end of the rainfall season. Consequently, a seedbed relatively free of weedy species is required for establishing the perennials. Once established on sites where they are well adapted, the deep-rooted perennial grasses will survive under competition from annuals.

Seed supplies of annual grasses, and the most competitive forbs, are scant under dense woody vegetation; special treatment usually is not required to reduce the weedy species if perennials will be sown during the first fall after removing dense brush. However, excessive weed seed probably will be present if sowing is delayed for one or more years. In open and semidense woody vegetation types, the seed supply of weedy species is fairly continuous over the soil surface, and it is usually present in amounts many times greater than the sowing rates for introduced perennial grasses. If so, special treatments are required to reduce the seed supplies and prepare a clean seedbed before perennial grasses are sown.

The cleanest seedbeds occur after hot fires in dense brush, wherever the heat from burning woody material was sufficiently intense to consume all of the litter and duff and destroy most seed over the soil surface (Bentley and Fenner 1958). The firm seedbeds, and the increased supply of soil nutrients during the first year after burning (Vlamis and Gowans 1961), are particularly favorable for first-year growth of perennial grasses.

Bulldozing or disking of dense brush does not destroy much seed of weedy species, but either removal method leaves a sufficiently clean seedbed. The seedbed surface may be looser than desired. Vigor of first-year growth of perennial grasses will be lower than on burned-over areas, particularly on soils of low native fertility.

A hot fire in semidense brush leaves a spotty supply of annual grass seed; generally the seedbed is satisfactory for sowing, particularly if the perennial grass seed is covered. If the fire in semidense brush was relatively cool and left much charred woody material and herbaceous stubble on the soil surface, the supply of annual grass seed tends to be fairly continuous; additional treatment is needed to prepare a clean seedbed.

Bulldozing or disking of semidense brush leaves too much annual grass seed, unless the brush is removed during late winter or early spring before the current seed crop has matured (fig. 37). Additional cultivation may be required before perennial grass is sown.

F-523589

Figure 37.—Stands of perennial grass such as this can be developed by drilling seed after double disking of medium density chaparral or crushing of light brush.

Hand clearing of brush seldom leaves a seedbed suitable for perennial grasses. Burning of litter, with weed control as needed, improves the seedbed condition.

On cleared brushlands where a ground cover of native and naturalized annual plants has become established, the stand of these plants must be destroyed before perennial grasses are sown. Fire in herbaceous vegetation does not develop sufficient heat at the soil surface to prepare an adequate seedbed. Repeated cultivation or application of a herbicide is needed to reduce the stand of competitive annuals.

A procedure sometimes employed on arable sites includes plowing, sowing, and harvesting of a cereal crop for 1 or 2 years, and sowing of perennial grasses during the fall or winter in the stubble. Another procedure is cultivation of natural herbaceous cover before maturity of seed in the spring, cultivation as needed to maintain a clean summer fallow, and sowing of perennial grasses in the fall. Both procedures can also include an additional cultivation after fall rains have germinated weed seed, just before the perennials are sown.

On wildland areas, to reduce competing vegetation ahead of perennial grass sowing, herbicides appear helpful because repeated cultivation often is not possible or is undesirable. Techniques developed for applying the herbicides have worked well in controlling annuals dominated by a single species, such as downy brome grass on the east side of the Sierra Nevada and Cascades. These techniques also show promise for the mixed annual plant covers in other parts of California.

Paraquat, a fast-acting contact herbicide rapidly inactivated on contact with soil (Weed Society of America 1967), can be applied at the time of drill sowing of perennials. Kay (1966) and Kay and Owen (1970) used a sprayer mounted on a rangeland drill to spray 11-inch bands over drill rows spaced at 22 inches, giving a 50 percent paraquat coverage at ¼ to ½ pound a.i. per acre. This spray-drill operation, applied after germination of annual range plants in the fall, produced vigorous perennial grass stands by the second year, whereas perennials sown on unsprayed areas did not survive the first year. In tests of sowing after spraying of paraquat at ½ pound per acre, mostly on sites in Nevada, Evans and others (1967) controlled downy brome grass and most other weeds, and established wheatgrasses on the treated areas. No injurious effects to wheatgrass seedlings were noted from rates of paraquat up to 3 pounds per acre. The manufacturer's recommended application is ½ pound a.i. of paraquat, plus 1 pint of X-77 spreader, in 100 gallons of water per acre, applied after fall rains have germinated annual weeds.

Use of some pre- and postemergence sprays, such as atrazine, simazine, and EPTC (ethyl N, N-di-n-propylthiolcarbamate) involves some risk of damage to perennial grass seedlings, particularly during dry years. But the success factor should be much greater than from seeding into a weedy seedbed. Kay and McKell (1963) found that 2 pounds a.i. per acre of simazine or 4 pounds of EPTC, applied during the fall, reduced a stand of annual grasses and forbs by about 50 to 70 percent, enough to allow establishment of a fair stand of spring-seeded hardinggrass. In northeastern California, simazine up to 2 pounds a.i. per acre and atrazine up to 1 pound reduced downy brome grass enough for "fair " wheatgrass establishment in a dry year (McKell and Kay 1964). In Nevada, Eckert and Evans (1967) found that atrazine at 1 pound per acre gave good control of downy brome and associated forbs, and allowed sowing of perennial grasses the following spring.

Suitable techniques for using herbicides to control competing herbaceous vegetation, as well as brush regrowth, are needed for establishment of introduced perennial plants—either grasses or shrubs—on fuelbreak sites covered with seed of competing aggressive annuals.

Sowing

Observations over many years have shown the most consistently successful grass stands have been obtained on cleared brushland areas by sowing with a drill or by covering of broadcast seed. Poor success has been the usual result from broadcast sowing without covering the seed on soils having a hard surface or on more favorable seedbeds during years of low or poorly distributed rainfall (fig. 38). The need for covering of the seed has not been fully appreciated because grass stands sometimes are established on brush burns by broadcast sowing without seed covering, where weather conditions are favorable. Covering of the sown seed wherever possible can be justified by the need to assure successful establishment of full stands during the first critical year.

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Figure 38.—Broadcasting perennial grass seed without covering resulted in a poor stand (foreground), but rolling with a brush roller following broadcasting produced a good stand (background). Drilling with the rangeland drill is generally best.

Best germination of grass seed and establishment of the small seedlings can be obtained if the seed is covered to depths of about ½ to 1 inch—the shallower depth for the smaller seed such as smilograss, big blue grass, and hardinggrass. The new seedlings develop better root systems and survive the vagaries of fall and winter weather better than seedlings established on the soil surface. The most uniform covering of seed can be obtained by sowing in the shallow troughs cut by the disks on a drill. Other mechanical equipment can be used for spreading and covering of the seed in one operation. Seed that is broadcast sown by hand or from the air can be covered in a nonuniform manner by dragging a roller, chain, or other device across the soil surface.

The rugged rangeland drill is the best equipment for sowing perennial grasses on wildland sites (fig. 39). Pulled by a small tractor such as the D-4, the drill can cover about 3 acres per hour on gentle terrain, with slopes up to about 40 percent gradient, if not impeded by rocks, stumps, or large shrubs. If many stems are left after a burn, a larger tractor with a wide blade is needed to break down the stems in the path of the drill. Large tough stems and sharp-sided gullies must be avoided when using a large tractor, to prevent excess strain and damage to the drill. Breakdown time and repair costs can make drilling very inefficient on rugged terrain.

Small seed or mixtures of small and large seeds can best be uniformly sown by mixing them with rice hulls, as described by Lemon and Hafenrichter (1947) and Hoglund (1948). The sowing rate can be calibrated, and uniformity of sowing in the rows can be checked, by jacking up and turning the drill wheel, and observing the flow of seed and hulls as it collects in cans or plastic bags.

Costs for sowing perennial grass mixtures depend in part on the species sown, but vary considerably for different methods of sowing and different conditions of the seedbed. The typical cost of a perennial grass mixture is about $5.00 per acre, but can be higher for the heaviest rates of hardinggrass. Drilling on a seedbed with few obstructions costs about $4.50 per acre for a small tractor and $5.50 for a larger tractor. Transport of equipment to the site adds about $2.00 per acre, but can be less on large jobs. Mileage, labor, supervision, and equipment maintenance add another $3.00 per acre. An average total cost, including seed, for drill sowing under favorable conditions is near $15.50 per acre. On burned areas, with many unburned stems, the slower progress and extra labor and maintenance costs bring the total cost estimate up to about $25.00 per acre.

Direct costs of broadcast sowing including costs for 50 percent more seed than is needed for drilling, and cost for transport of a helicopter to the site, are about $10.00 per acre. Covering of the seed by pulling a chain or roller behind a large tractor costs

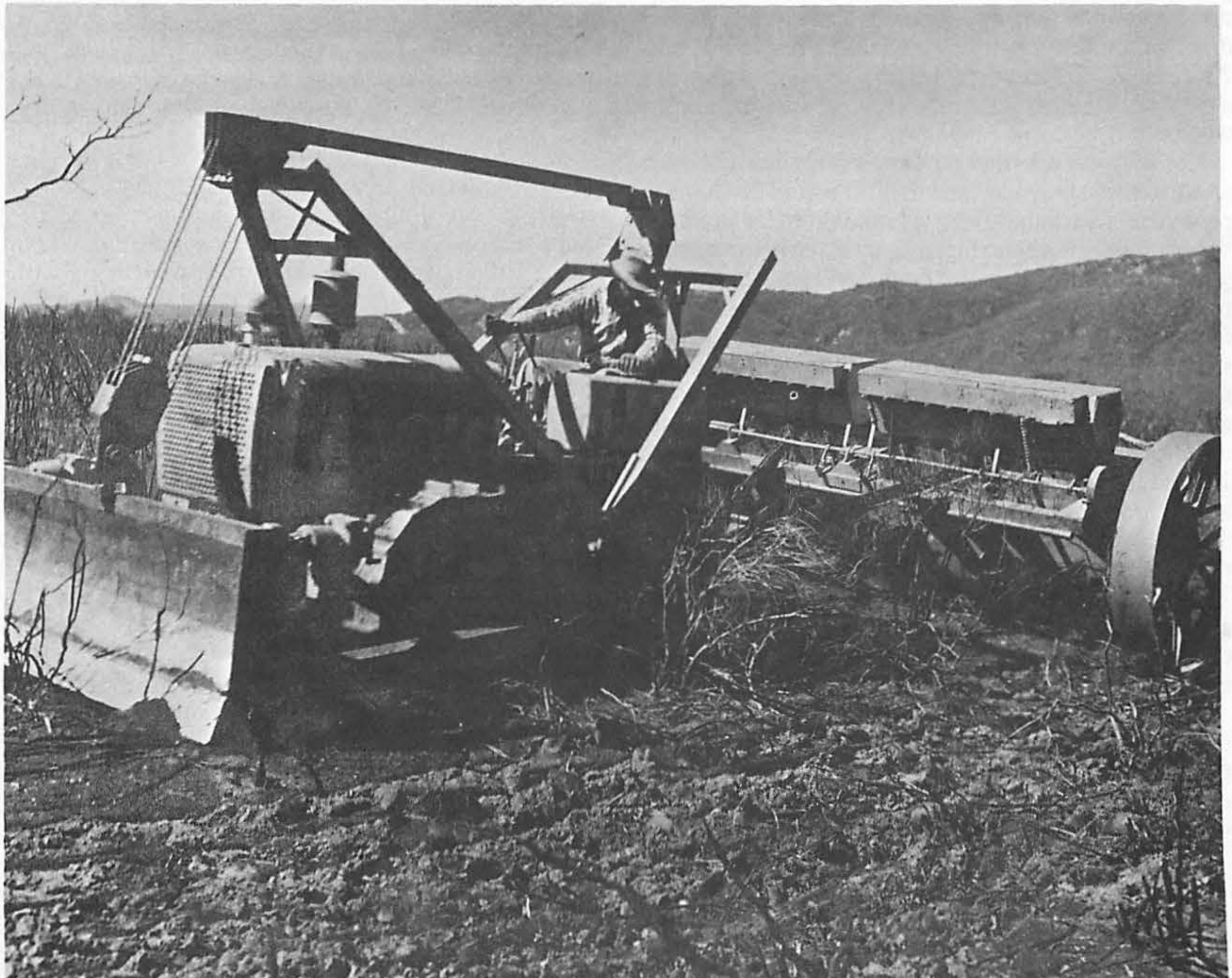

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Figure 39.—The rangeland drill is the only large drill rugged enough for use on wildland sites, and it can be damaged. A dozer blade carried just above the soil surface is some insurance against damage.

about $6.00 per acre, bringing the total cost for helicopter sowing and mechanical covering of the seed up to $16.00 per acre. Broadcast seed has also been covered by dragging a light anchor chain between two tractors on suitable terrain.

Maintaining Perennial Grass Covers

Workers generally agree that livestock grazing of perennial grass stands is not advisable during the first year of establishment, and that perennial grasses are more vigorous and persist better if properly grazed, rather than left ungrazed, after the stands have become established. Fuelbreaks, and other areas where established perennial grass stands provide an improved ground fuel situation, can be well managed where they are part of ongoing range operations. Unfortunately, however, many fuelbreaks include limited acreage remotely located and poorly watered. These areas are left ungrazed, except by wildlife, or have been poorly managed.

Systems of grazing now generally used on western rangelands can be adapted for management of wheatgrass stands, at least on mountain lands where winters are cold and competing annuals are dominated by downy brome grass or similar species. But grazing systems have not been devised nor proved by trial on the foothill areas having mild winters and long, hot summers, where hardinggrass and other perennials must compete with a very aggressive mixture of annuals. In short, research has shown how to establish perennials on foothill ranges but not how they can best be managed. Obviously, however, they cannot be closely grazed continuously year after year.

One problem is that perennial grass stands have been established in the foothills and lower mountains on sites where fertility level is relatively high during the years immediately after burning dense stands of chaparral. Grass production will support relatively high stocking, up to 1.0 or more animal unit months per acre. As grass growth drops off to natural site productivity, the perennial grasses lose vigor and are damaged by the same degree of continued heavy grazing. We have not learned how stocking should be adjusted to changing site productivity.

Legumes are needed within the grass mixtures to maintain a desirable level of soil fertility. With few exceptions, the legumes have not been well established from sowing trials on cleared brushland areas in California. One reason is that they require more phosphorus or sulfur, or both, than most soils provide. Another is that they can be damaged by herbicide treatments needed to control early brush reinvasion. Consequently, the legumes are seldom included with perennial grasses for initial establishment of a ground cover. More work certainly is needed to determine the possibilities for adding legumes to the established cover, and the fertilization practices needed to promote growth of legumes. Annual legumes have been established most successfully within the natural cover on many sites below the brushland areas.

Herbaceous covers containing perennial grasses have effectively prevented establishment of new brush seedlings on many areas. On the Grindstone Canyon test area on the Mendocino National Forest, where chamise chaparral was burned and perennial grasses sown in 1957, herbicide spraying in 1958 and 1959 left scattered brush plants which were kept closely hedged by deer and cattle. Almost no new brush seedlings had become established after 15 years. In contrast, on adjacent burned areas not sown and sprayed, a dense brush cover had developed. Similarly, on a fuelbreak within the mixed conifer zone on the west side of the central Sierra Nevada, a solid stand of perennial grasses prevented invasion of brush and conifer seedlings for 5 years after grass establishment, whereas unsown areas were thickets of pine and manzanita seedlings (Schimke and others 1970).

Low-Volume Woody Ground Covers

Small woody plants—semishrubs—of low total volume per acre could have fuel characteristics superior to the flammable grasses, in which fire ignites readily and spreads rapidly (U.S. Department of Agriculture, Forest Service—California Region 1956). For use as fuelbreak ground covers, the woody species must be relatively slow burning when alive and sufficiently aggressive to restrict growth of herbaceous annuals and to retard establishment of tall-growing shrubs after these have once been eliminated from the site.

After removal of heavy woody fuels, the establishment of low-volume woody plants presents special problems, if they are not naturally present in dense stands. Seed is generally not available and must be collected from natural stands or seed orchards established. Methods for breaking seed dormancy or for rooting cuttings must be developed. Broadcast herbicide applications cannot be used, as in grass covers, to control the initial thick stand of native brush regrowth. Intensive cultivation, or other treatment, is needed to control aggressive herbaceous plants until the slow-growing woody cover has become established.

After establishment, selective hand treatments may be needed to control any heavy woody vegetation that also becomes established, unless it can be killed by prescribed burning without destroying the ground cover. Repeated applications of preemergence herbicides may be needed to control flammable annual grasses. And periodic prescribed burning is usually required to remove accumulations of dead woody litter, pine needles, or similar dry fuel that is highly flammable.

Natural Semishrub Ground Covers

The naturally occurring semishrub most successfully used for fuelbreak ground cover is bearmat. It grows in the ponderosa pine and mixed conifer forest on the west side of the Sierra Nevada. After removal of heavy undergrowth fuels and thinning of the overstory tree canopy, the bearmat usually thickens in the extensive patches where it naturally occurs. It protects the soil and hinders establishment of heavier brush and conifer reproduction. However, occasional prescribed burning is needed to reduce the volume of bearmat and to remove accumulations of dead woody stems and pine needles. The burning also aids in control of invading tall woody plants.

Where present in extensive stands, the bearmat tends to hold the fuelbreak in a rather stable situation. Bearmat burns readily but does not produce heavy firebrands that cause spot fires; it definitely is less flashy fuel than dense annual grass cover. Dense stands of perennial grasses on the more open spots not occupied by bearmat make equally satisfactory stable covers.

Artificially Established Semishrub Ground Covers

Firefighters have long wished for ground covers that were less flammable than annual grasses and that would burn with lower heat output than most brush species. In California, the search began in 1928 when the Forest Service started test plantings of ice plants (*Mesembryanthemum* spp.), woody spurges (*Euphorbia* spp.), and other succulents in the San Bernardino Mountains. These plants succumbed to browsing, summer drought, or low winter temperatures (Ilch 1952). Recent effort has been directed toward finding low-growing ground covers that ignite less readily and burn slower than shrubs labeled "greasewood."

Moisture content is generally recognized as the primary cause of variation in flammability; the moisture content of small fuels is basic to all computations in wildland fire danger rating systems. The rate of fire spread has been determined to be, generally, inversely proportional to fuel moisture content (Byram 1959; Fons 1946).

Most plants are higher in moisture content during the spring than later in the season; young plants, or young shoots, contain more water than older growth; and live growth contains much more moisture than dead shoots. Thus, plants may be resistant to fire during the spring, but not later. Young chaparral may not burn, whereas stands older than about 10 years gradually become more hazardous as ground litter and dead twigs and branches on live plants slowly build up. Drought periods increase the rate of dead fuel accumulation, and also reduce the moisture content of live fuels (Buck 1951; Pirsko and Green 1967).

Fuel moisture is only one of a number of influences on flammability, and it is nearly always associated or interacting with others. Chemical or ash content is another influence, and evidence now accumulating indicates that inorganic content may affect the way plants ignite and burn. Adding as little as 1.5 percent by weight of the fire extinguishing agent $KHCO_3$ to pure alpha-cellulose prevented sustained flaming, but increased the tendency to glowing combustion (Broido and Martin 1961). Corn plants, cut while green, then stored under cover, flamed when lighted with a match but the flames died promptly when the match was removed. Leaves from corn plants that had weathered over winter were consumed. The difference in flammability was credited to difference in ash content—11.4 percent in the slow-burning sample harvested green and 3.7 percent in the other (Broido and Nelson 1964).

There was a high degree of correlation between leaf flammability and mineral content of numerous Australian forest species, flammability decreasing as mineral content increased (King and Vines 1969). Philpot (1970) studied chemical and burning characteristics of brush and trees with a wide range in mineral content. He found the maximum rate of weight loss, amount of volatilization, and temperature at which plant materials underwent thermal decomposition were related to the mineral content, especially phosphorus and calcium. Chemical analysis of chaparral that supported fast-moving test fires in Arizona showed about half the phosphate phosphorus content of slower burning chaparral. A breaking point seemed to occur at 0.235 percent; below this, contingent rate of spread increased (Lindenmuth and Davis 1973). Diammonium phosphate retardant applied to herbaceous plant growth along Interstate 5 through the Angeles National Forest is credited with almost eliminating fire escapes along the highway (Davis 1971).

Just what the implications of ash content for modifying chaparral flammability may be we do not know. In one laboratory test, increasing the wind velocity equalized the rate of burning of "resistant" and "nonresistant" plant litters, and increasing density by compaction of brushy fuels canceled out the effect of high ash content (Friedman and Waisel 1966). Accumulation of dead branchwood and litter has also obliterated the effect of ash content in

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Figure 40.—Creeping sage is a promising low-volume plant for fuelbreaks. It is competitive with annuals, green during the summer, and retards fire spread. Methods for its propagation have been developed.

fourwing saltbush (*Atriplex canescens* (Pursh) Nutt.) which burned to the ground (pers. commun., Eamor C. Nord).

Several saltbushes are of interest, because of relatively low growth habit, and high salt and moisture content.[28] Gardners and Castlevalley saltbushes (*Atriplex gardneri* (Moq.) D. Dietr.), *A. cuneata* A. Nels.) have been established by direct seeding in southern California. They are woody at the base, with decumbent or creeping stems. They spread by underground root sprouts or by layering (Nord and others 1969). This vegetative reproduction is very important under adverse growing conditions. Mullers saltbush (*A. mulleri*) and Australian saltbushes are low-growing, usually biennial species. Allscale or desert saltbush (*A. polycarpa* (Torr.) Wats.), fourwing saltbush, and quailbush (*A. lentiformis* (Torr.) Wats.) are taller species that are widely adapted to dry disturbed situations. Seed of these species can be collected readily during the fall of some years, October to November 15 for allscale, and late into December for fourwing saltbush. Some commercial seed dealers will supply seed, but needs should be anticipated 2 years ahead of the planting date.

A low-growing plant of primary interest is creeping sage (*Salvia sonomensis* Greene) (fig. 40). It forms dense mats where it occurs on dry mountain slopes and ridges in both central and southern California below 6,000 feet elevation. It has value for soil holding, and also for reduction of density of annual plants that are very flammable when dry. Its seed must be stratified at cold temperatures for 90 days prior to seeding, or soaked in a 500 p/m gibberellic acid solution for 4 hours shortly before seeding to induce and hasten germination. Seed should be planted at ½ to 1 inch depth during the early spring in a clean seedbed (Phillips and others 1972). Potted transplants and freshly cut stem or branch sections at least 12 inches long, and set at least 6 inches into moist ground during early spring, have rooted and survived well, and made rapid growth (Nord and Goodin 1970).

Long-Term Management of Ground Covers

Long-term vegetation fuel management of wildland areas begins after old woody material has been reduced and sprouting brush plants have been eliminated to the desired level. On type conversion areas, brush removal, cover establishment, and followup control of brush regrowth take at least 3 years. Within conifer types, including new pine plantations, the control of brush and thinning of conifers to the desired density often takes 5 years or longer. Gradual reduction of woody material by prescribed burning, not supplemented by fuel preparation and herbicide treatments, can extend over a much longer period—in a sense it is a long-term management practice with limited and uncertain results as compared to more intensive fuel reduction practices.

In management of ground covers, the aim is to keep total dry fuel volume at a low level, arbitrarily set at 2 tons dry weight per acre in southern California (Fuel-Break Executive Committee 1963). A cover of grass and its litter weighs near 1 ton per acre, except on the most productive sites. Moderate grazing can keep the buildup of burnable fuel below 1 ton per acre. Control treatments such as periodic prescribed burning, if applied on ungrazed range, are intended to remove current flammable fuel, reduce litter that favors growth of tall annual grasses, and destroy new woody plant seedlings within the grass stand. Proper grazing can maintain herbaceous ground covers on productive sites, except for any needed hand treatments to kill scattered plants of invading brush. On low productivity sites, where dense stands of new woody plants may be quickly established, broadcast spraying or burning may be needed periodically.

Scattered small shrubs within a grass stand, or under conifers, add to the total volume of ground cover, and may increase average weight of this vegetation to more than 2 tons per acre. But they do not add greatly to the fuel hazards, unless litter and dead stems become sufficiently heavy to ignite the

[28] Nord, Eamor C., and Lisle R. Green. Low volume and slow burning vegetation for planting on clearings in California brushland. Manuscript in preparation. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

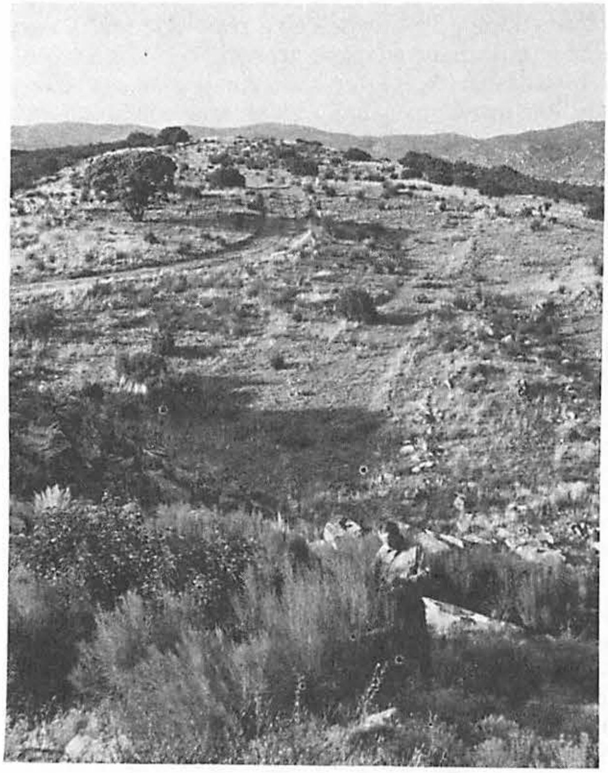

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Figure 41.—Scattered brush such as this gradually reduces fuelbreak effectiveness. Hand spraying or pelleted herbicide application around individual shrubs may be the best treatment.

brush and spread firebrands. Periodic prescribed burning can reduce the dry fuel, and browsing by wildlife can keep the woody plants in check.

Fairly continuous stands of shrubs, which add dry litter and stems within a dry grass cover, build up a hazardous fuel condition (fig. 41). The ground cover becomes highly flammable, and heat output from the increased fuel volume adds greatly to the problems of fire control.

A new stand of invading shrubs having an average spacing of 6 feet between plants has a dry weight of about 0.5 ton per acre of leaves, twigs, and small stems when the plants average 2 feet in diameter and 2 feet in height, assuming 150 pounds per 1,000 cubic feet of crown (Bentley and others 1970). If diameter is 3 feet and height 3½ feet, the dry weight of small material is between 2.0 and 3.0 tons per acre; if both are 4 feet, it is about 5 tons; and if diameter is 6 feet and height 7 feet, it is 10 to 20 tons—with a buildup at all stages in large stems and in ground litter. Management practices must be aimed at keeping the potential fuel well below these levels. Broadcast spraying of herbicides and/or prescribed burning will be needed if brush stands of this density become established.

Standard Maintenance Treatments

The same tools—prescribed burning, herbicide treatment, or use of mechanical equipment and manpower—used for initial removal and control of brush are also used in the long-term maintenance operations.

Thin stands of brush plants, if not adequately kept in check by browsing, are best eliminated by hand treatments, such as grubbing or chemical application. If new brush plants are too numerous for economical hand treatments, and if burnable fuel is continuous and adequate in amount, prescribed burning, while the brush plants are still small, appears to be most feasible. Prescribed fire has proven effective for maintaining fuelbreaks in the central Sierra Nevada (Schimke and Green 1970). It has been effectively used in trials on grassy fuelbreaks in brushland types, even when grass was burned before it had fully dried (fig. 42). Where fire cannot be safely used, or if dry fuel is too scant for effective burning, broadcast herbicide application on the small brush plants is effective. In all situations, dense stands of new brush seedlings should be treated while they are small and susceptible to fire or herbicides. Otherwise, control of woody plants requires what is virtually a new land clearing operation.

Selective Browsing

A sound approach to long-term vegetation-fuel management on areas cleared of heavy brush would be reduction of shrubby plants to a point where browsing by animals would hold them in check, supplemented by livestock grazing to maintain herbaceous vegetation in a satisfactory condition. Opportunities for this ideal approach do not presently exist on much of the California wildland area, but attempts can be made to develop situations where browsing adds to control of brush reinvasion.

Deer.—Browsing by deer will reduce the dense stand of sprouting brush to the extent needed for fuel management if only small areas are cleared at one time. Sampson (1944) concluded that local deer populations in northern California would control sprouting brush on areas no larger than 4 to 5 acres. On one ranch site near Santa Maria in southern California, deer browsing killed sprouts of Coast live oak (*Quercus agrifolia* Nee.) if only a few trees were cut each year; after cutting of two or several acres in one year, the deer hedged the sprouts but killed none of them. When several hundred acres of oaks were burned in a wildfire, the deer browsing had no effect in controlling regrowth. Similar situations have been observed in burned-over chamise (Buttery and others 1959).

Heavy brush commonly is removed from areas too large for followup control by deer alone; drastic re-

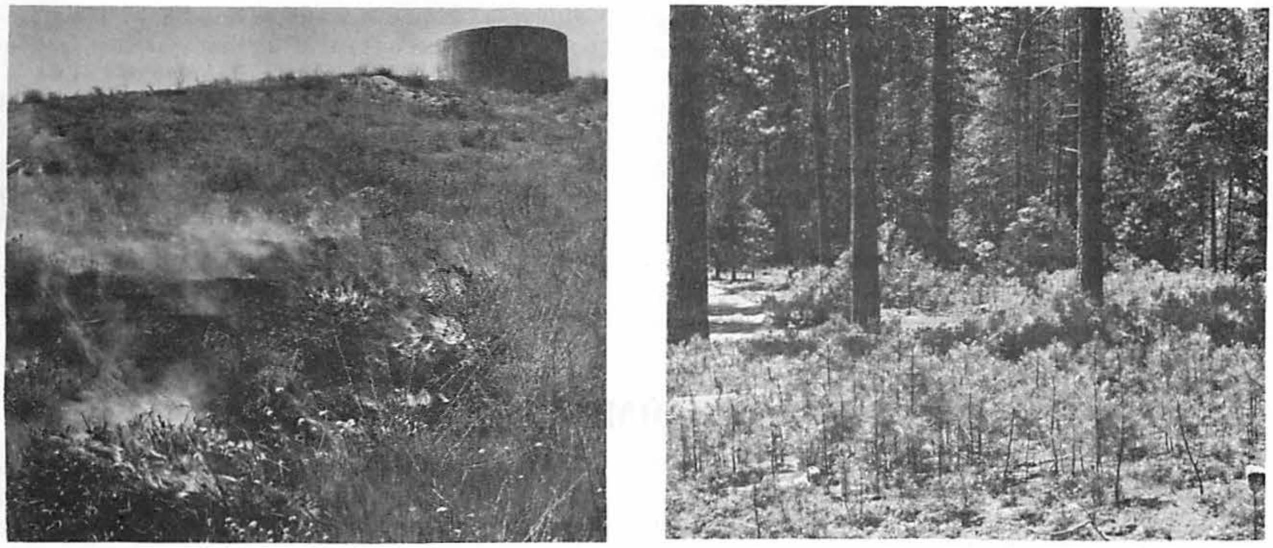

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Figure 42.—Prescribed fire at intervals of several years is valuable for maintaining fuelbreaks clear of unwanted fuel accumulation. Here (left) excess grassy fuel is burned on a fuelbreak, whereas (right) in a mixed conifer forest clearing, too much fuel has accumulated.

duction of sprouting plants is needed before browsing becomes an effective control measure. The elimination of rapidly invading brush should always be terminated, however, when current browsing by deer equals a significant portion of current brush growth.

As a basic part of project planning, all fuel reduction operations should provide for improvement of wildlife habitat and for the greatest possible use of any new supply of palatable browse. This can be done by wise location of cleared areas to provide maximum border effect near escape cover, by adjusting shape of cleared areas as needed, and by leaving islands of heavy brush inside otherwise cleared areas (Biswell and others 1952). Fuelbreaks can be made more effective by gradual removal of old brush on small areas adjacent to the breaks, where heavy use by deer will keep hazardous fuel at a low level.

Domestic livestock.—Well-managed livestock grazing, in addition to maintaining the herbaceous ground cover, can help control reinvasion of small brush plants. Goats eat more browse than sheep, which in turn eat more than cattle and these animals may be ranked in that order for effectiveness in reducing brush (Wilson 1969). In central California, cattle browsing was of small consequence when green forage was abundant, and of minor importance the rest of the year. On the average, only about 3.6 percent of their total feeding time was spent browsing, and this amounted to only 1 or 2 percent of the diet (Green and others 1958; Wagnon 1963). Sheep grazing does not eliminate established dense stands of sprouting species, unless combined with repeated burning, and carried out at a level that results in excessive use of the herbaceous ground cover. But sheep can greatly retard reinvasion of new brush plants and reduce the need for other brush control treatments. Sheep grazing has possibilities as a treatment on fuelbreak areas, even though it may require subsidizing an uneconomical livestock operation.

Goats have often been used successfully to eliminate or control regrowth of brush (Bredemeier 1973; Davis and others 1975; Flynn 1973; Huss 1971, 1972). They do not control dense mature brush stands, however, unless confined within very small areas. Adequately confined at the necessary heavy stocking, goats then over-use the entire vegetation cover unless their grazing is carefully managed and rotated (Allred 1949; Elam 1952). Because of the good fencing required, along with provision for water and proper care, goats have had limited use as a major brush control measure on California wildlands. However, interest in their use is increasing. Research underway has demonstrated that regrowth following fire or mechanical clearing can be killed or controlled by goat browsing, without damaging the herbaceous cover. And herding of large flocks on fuelbreaks or burned areas can eliminate most fencing. Goat grazing, like sheep grazing, has best possibilities as a means of retarding brush growth when other treatments provide the major brush removal.

In summary, browsing alone or in combination with mechanical clearing or burning of dense brush has established stable vegetation on only limited areas, as discussed by Leonard and Carlson (1958). However, if mature brush can be removed by combinations of hand or mechanical operations, combined with burning or herbicide treatment, and the land fenced or the goats or sheep herded, browsing can contribute greatly to brush control on many areas.

Other Biological Control Methods

Insects or pathogens have so far offered little possibility for control of heavy brush species in California. However, improvement and maintenance of herbaceous cover on many areas in northern California has been greatly enhanced since introduction of Chrysolina beetles for control of Klamath weed (*Hypericum perforatum* L.) (Murphy and others 1954; Huffaker and Kennett 1959; Holloway 1964). Natural control of another weedy herbaceous species, tansy ragwort (*Senecio jacobaea* L.), shows promise, indicating possible future accomplishments in control of objectionable wildland plants (Cameron 1935).

SUMMARY

Mediterranean climate and rough topography, both present in California wildland, combine to produce hazardous fuel conditions with high potential for large fires. The shrubby plant covers burn readily; coniferous forest typically includes dense stands of brush or coniferous understory. The result is frequent large fires, with suppression costs averaging around $100 per acre, and postfire damage from flooding and erosion.

The Fuelbreak Concept.—The fuelbreak concept developed as an approach to the fire control problem in California. The Fuel-Break Research and Demonstration Program was organized by the principal wildland firefighting agencies in southern California and given the broad assignment, "Develop, test, and evaluate methods for breaking up or otherwise modifying expanses of brush or other wildland fuels to facilitate fire control." This report summarizes research accomplished by the Program, and pertinent research from other sources.

The fuelbreak concept essentially provides that expanses of heavy woody fuel be broken up at strategic locations by wide blocks or strips of lighter cover. This new cover may be resident herbaceous annuals, perennial grasses on suitable sites, bearmat in some timbered areas, or suitable introduced ground cover. Frequently included within these wide "fuelbreaks" are firelines from which backfiring may be done. Hazardous fuels are cleaned up on these limited fuelbreak areas, as it is impractical to treat fuels on all wildland.

Fuelbreak type conversion is primarily aimed at fire control, but also has value for wildlife habitat improvement, increased forage or timber, and improved access for recreationists. Fuelbreaks have frequently been advantageous in stopping fires, though usually not under extreme burning conditions. A fast-moving fire that is spotting far ahead of the fire front cannot be stopped by a fuelbreak.

Fuelbreak locations are generally chosen for protection of urban development or natural resources. Ridgetops are usually preferred. A system of fuelbreaks is desirable. Fuelbreak widths are determined by terrain, fuels, and expected weather conditions, as well as by economic considerations. A suggested minimum is 200 feet; many fuelbreaks are wider, however.

Removal of Vegetation by Hand or Machine.—Many miles of fuelbreak have been cleared by hand, mostly with low-cost inmate labor, which is not presently available in quantity. The high cost of labor now limits hand clearing to small areas, or to uses that facilitate machine operations. Costs (1974) might run from $450 per acre for light brush to $1,200 or more for heavy brush.

Mechanical brush removal is more efficient than hand cutting, but can have the adverse environmental result of unsightly visual effect, with increased erosion and sedimentation. Costs for removing brush and pushing it into piles with a bulldozer on gentle to moderate slopes are about $25 per acre in light brush, and $45 to $65 in heavy brush. Costs may be double this on steep slopes. Heavy offset disks are effective in light-to-medium brush, and frequently serve to prepare the site for drill seeding. Single disking of light brush on gentle terrain cost $25 to $30 per acre on slopes up to 35 percent. Bulldozed brush must usually be disposed of by burning; disked brush generally does not need such treatment. Brush has been buried, or chipped, but this is expensive.

Prescribed Burning.—Prescribed or broadcast burning is the planned use of fire for removing vegetation in place over part or all of a designated land area. Such burning is generally done under a "prescription," or established set of limits on burning conditions, including maximum and minimum temperature, humidity, wind, and fuel moisture. Burning of grassy fuels must be done during the dry season, or at the end of the green season. Moisture content of the grass should be below 30 percent, winds less than 8 miles per hour, and relative humidity 25 to 40 percent if green woody fuels are to be consumed but up to 50 percent otherwise. Air temperature should be below 85° F.

Heavy woody fuel in its natural state seldom burns well under prescribed weather conditions. Consequently, methods have been developed for preparing brush fuels ahead of burning so that more of the woody material will be consumed. Crushing is generally most effective for plants with brittle stems. Young plants with limber stems must be sprayed with herbicide.

Crushing can be done with a bulldozer, with the blade carried about a foot above the ground, at a cost of about $12 per acre for medium brush. An anchor chain between two large tractors works well on uniform terrain. Costs for two passes of the chain average about $20 per acre. Ball-and-chain crushing works well where the tractor can travel along a ridgetop above slopes greater than 30 percent.

Quick-acting contact herbicides kill exposed leaves and small tender twigs, but this does not greatly assist burning of green stems. To accomplish this, the slower acting systemic herbicides such as 2,4-D are recommended because they kill more of the stems. Spraying is generally best done one year and burning the next year.

The prescription for burning an area of brush or forest fuels spells out the objectives to be attained, fuel preparation required to assure results, and safe conditions for conducting the burn are specified by knowledgable people. When burning is done according to the prescription, escapes are rare.

Hot fires are generally the rule in successful brushfield burns, but in the mixed conifer forest, removal of excess dead fuel and kill of unwanted green stems is best accomplished by fires of relatively low intensity. Burning is usually accomplished safely and with least damage to soil during late winter or early spring.

Herbicides.—Following brush removal by any means, regrowth from crown sprouts or seed begins, and this woody regrowth must be controlled to maintain effective fuelbreaks. Herbicides are particularly well suited to the purpose because they are selective, can be applied readily on rough rocky terrain, have minimal impact on the environment, and are sufficiently effective in most vegetation types.

The systemic herbicides of greatest importance for controlling California brush are 2,4-D and 2,4,5-T. Silvex, picloram, and amitrole are of lesser importance. The low-volatile esters have been more effective than the amine formulations. A "brushkiller" mixture of 2 pounds each of 2,4-D and 2,4,5-T in 1 gallon of diesel oil and 9 gallons of water has been widely used, but 2,4-D, alone or with ½ to 1 pound of picloram, is used where 2,4,5-T is not required. Silvex has been effective on some oaks and on poison oak. Picloram use has been limited by cost, and by its persistence in the environment, but it is effective on a wide variety of shrubs. Ammate is used where the phenoxy herbicides present excessive hazard to sensitive vegetation.

Herbicides are generally applied as foliar sprays, particularly where plants occur in dense stands. This application is most economical, but is limited by potential danger from spray drift, by requirements of seasonal timing (particularly in dry situations) and plant size (preferably first or second growing season). Three sprays during successive years are necessary to control most brush species. Tractor boom spraying is frequently more effective than aerial spray, and hand application to individual plants is still more effective. This method requires coverage of the entire plant, to the point of saturation. The method is expensive, with expected costs of $75 per acre.

Bark sprays are used for shrubs with crowns too large to spray. The bark may be sprayed thoroughly from below ground level to a height of 12 to 14 inches with a mixture of 2,4-D and 2,4,5-T, or 2,4,5-T alone, combined with diesel oil at 16 pounds a.e. per 100 gallons. On large stems, undiluted 2,4-D amine can be injected or squirted into ax cuts around the stem. Shrubs or trees can be cut, and herbicide applied to the fresh stumps.

Three pelleted herbicides—picloram, fenuron, and karbutilate—have been effective for applying on the ground around individual plants, or for broadcasting if plants are thick.

Diuron proved effective as a sterilant for most locations, at 20 to 30 pounds per acre, although monuron and bromacil were more effective on the driest sites. Fenac eliminated broadleaved plants, but not grass. Effects from monuron, diuron, and simazine lasted for at least 3 years. At 1.6 pounds active ingredient (a.i.) per acre, atrazine effectively limited growth of native annual grass, while not interfering seriously with deeper rooted perennial species.

Establishing and Maintaining Ground Covers.—As part of a type conversion process, establishment of ground covers is started soon after initial removal of woody material. Site productivity and future dominant land use determine selection of species. If no action is taken to prevent it, a cleared site will soon be occupied by annuals, especially grasses, and on dry shallow soils, this may be the most suitable cover. As added insurance for a protective soil cover, annual ryegrass may be sown at about 8 pounds per acre. If reinvasion by woody plants is kept under control, a herbaceous cover will persist many years.

Perennial grasses are the plants most widely planted on California wildlands to improve fuel and forage characteristics and to restrict reinvasion of brush seedlings. A soil with water storage capacity of 3 to 4 inches or more in the upper 3 feet is needed.

At least 20 inches average annual precipitation is required, except near the coast. Hardinggrass and intermediate and pubescent wheatgrasses are three of the best for brushland planting. A clean seedbed is essential for establishing perennials, and the seed must be covered. Sowing with the rangeland drill is the best method available. Cost of seed and drill sowing is about $15 per acre on good site. Livestock grazing is not advisable the year of establishment, but perennial grasses are more vigorous after that if moderately grazed.

Because perennial grasses are flammable when dry, attempts have been made to establish low-growing woody plants that would burn with lower heat output in the event of wildfire. Progress has been slow because seed is not available commercially, methods for breaking seed dormancy or for providing root cuttings must be developed, broadcast herbicides cannot be used to control brush regrowth, and clean seedbeds are required. Bearmat in the mixed conifer forest is a good ground cover shrub. Among artificially established subshrub ground covers, creeping sage is most promising. Some saltbushes are low growing, and have a high twig moisture and salt content that combine to make them resistant to fire.

Management of ground covers aims at keeping total dry fuel volume at 2 tons per acre or less. Moderate grazing of annual or perennial grass covers easily accomplishes this. Periodic prescribed burning can reduce current fuel, reduce litter, and destroy new woody plant seedlings. Herbicides, mechanical equipment, or hand labor can also be used to maintain ground covers on fuelbreaks. Browsing animals, especially goats, where they can be herded, offer possibilities for control of brush regrowth.

LITERATURE CITED

Akesson, Norman B., S. E. Wilce, and W. E. Yates.
1971. Confining aerial applications to treated fields—a realistic goal. Agrichem. Age 14(2):11, 13–14.

Allred, B. W.
1949. Distribution and control of several woody plants in Texas and Oklahoma. J. Range Manage. 2(1):17–29.

Arnold, Keith, L. T. Burcham, Ralph L. Fenner, and R. F. Grah.
1951. Use of fire in land clearing. Calif. Agric. 5(3–7):9–15.

Bayer, David E.
1963. 2,4-D—factors affecting its performance. Agrichem. West 6(8):7, 16–17.

Bayer, David E.
1965. The role of surfactants in weed control. 17th Annu. Calif. Weed Conf. Proc., Fresno, p. 90–92.

Behrens, R.
1957. Influence of various components on the effectiveness of 2,4,5-T sprays. Weeds 5:183–196.

Bentley, Jay R.
1961. Fitting brush conversion to San Gabriel watersheds. USDA For. Serv. Misc. Pap. 61, 8 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Bentley, Jay R.
1967. Conversion of chaparral areas to grassland: techniques used in California. U.S. Dep. Agric. Handb. 328. 35 p.

Bentley, Jay R., Lester J. Berry, Donald R. Cornelius, and Merton R. Love.
1956. Range species recommended for sowing on cleared brushland in California. USDA For. Serv. Res. Note 111, 10 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Bentley, Jay R., C. Eugene Conrad, and Harry E. Schimke.
1971. Burning trials in shrubby vegetation desiccated with herbicides. USDA For. Serv. Res. Note PSW-241, 9 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Bentley, Jay R., and Kenneth M. Estes.
1965. Use of herbicides on timber plantations. USDA For. Serv. Calif. Reg. and Pac. Southwest For. and Range Exp. Stn., San Francisco, Calif. 47 p.

Bentley, J. R., and R. L. Fenner.
1958. Soil temperatures during burning related to postfire seedbeds on woodland range. J. For. 60(10):737–740.

Bentley, Jay R., and Charles A. Graham.
1976a. Applying herbicides to desiccate manzanita brushfields before burning. USDA For. Serv. Res. Note PSW-312. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Bentley, Jay R., and Charles A. Graham.
1976b. Rating effectiveness of herbicides in desiccating woody vegetation. USDA For. Serv. Res. Note PSW-311. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Bentley, Jay R., Lisle R. Green, and A. B. Evanko.
1966. Principles and techniques in converting native chaparral to stable grassland in California. 10th Int. Grassl. Congr. Proc., p. 55–59. (Helsinki, Finland).

Bentley, Jay R., Donald W. Seegrist, and David A. Blakeman.
1970. A technique for sampling low shrub vegetation by crown volume classes. USDA For. Serv. Res. Note PSW-215, 11 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Bentley, Jay R., and Verdie E. White.
1961. The fuel-break system for the San Dimas Experimental Forest. USDA For. Serv. Misc. Pap. 63, 9 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Biswell, H. H.
1959. Reduction of wildfire hazard. Calif. Agric. 13(6):5.

Biswell, Harold H.
1960. Danger of wildfires reduced by prescribed burning. Calif. Agric. 14(10):5–6.

Biswell, H. H., R. P. Gibbens, and Hale Buchanan.
1968. Fuel conditions and fire hazard reduction costs in a Giant Sequoia Forest. Calif. Agric. 22(2):2–4.

Biswell, H. H., R. D. Taber, D. W. Hedrick, and A. M. Schultz.
1952. Management of chamise brushlands for game in the north coast region of California. Calif. Fish and Game 38(4):453–484.

Blanford, Robert H.
1962. The North Mountain Project of land treatment for fire protection. Calif. Div. For., Sacramento. 17 p.

Bovey, R. W., F. S. Davis, M. C. Merkle, and others.
1965. Defoliation and control of brush. Proc. South. Weed Conf. 18:288–292.

Bovey, R. W., C. C. Dowler, and J. D. Diaz-Colon.
1969. Response of tropical vegetation to herbicides. Weed Sci. 17(3):285–290.

Bower, R. W.
1963. Management designs for conflagration control, Duckwall test unit. Fire Control Notes 24(3):51–55.

Bredemeier, Lorenz F.
1973. Managing plant communities by means of animals. West. Livestock J. 51(33):23, 32, 35–36, 38.

Britton, Carlton M., and Henry A. Wright.
1971. Correlation of weather and fuel variables to mesquite damage by fire. J. Range Manage. 24(2):136–141.

Broido, A., and S. B. Martin.
1961. Effect of potassium bicarbamate on the ignition of cellulose by radiation. Fire Res. Abstr. and Rev. 3(3):193–201.

Broido, A., and M. A. Nelson.
1964. Ash content: its effect on combustion of corn plants. Science 146(3644):652–653.

Bronson, A. H.
1954. A yardstick for nonselective weed oils. 14th West. Weed Control Conf., Tucson, Ariz., 100 p.

Buck, Bill.
1971. Rx for burning on Apache National Forest. Fire Control Notes 32(1):10–12.

Buck, Charles C.
1951. Inflammability of chaparral depends on how it grows. USDA For. Serv. Misc. Pap. 2, 2 p. Calif. For. and Range Exp. Stn., Berkeley, Calif.

Burcham, L. T.
1959. Planned burning as a management practice for California wildlands. Soc. Am. For. Proc., San Francisco, p. 180–185.

Butler, B. J.
1967. New additives to reduce herbicide drift. 19th Annu. Calif. Weed Conf. Proc., San Diego, p. 62–69.

Buttery, R. F., J. R. Bentley, and T. R. Plumb, Jr.
1959. Season of burning affects follow-up chemical control of sprouting chamise. USDA For. Serv. Res. Note 154, 11 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Byram, G. M.
1959. Combustion of forest fuels (Chapter 3) and forest fire behavior (Chapter 4). *In* Forest fire: control and use. K. P. Davis, ed. McGraw-Hill Book Co., New York.

California Division of Forestry.
1974. Brushland range improvement—1973 annual report. Calif. Div. For., Sacramento, 13 p.

Cameron, E.
1935. A study of the natural control of ragwort (*Senecio jacobaea* L.). J. Ecol. 23(2):265–322.

Carpenter, Stanley B., Jay R. Bentley, and Charles A. Graham.
1970. Moisture contents of brushland fuels desiccated for burning. USDA For. Serv. Res. Note PSW-202, 7 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Casamajor, Paul, and Carl C. Wilson.
1957. Portable chippers—answer to reducing slash fire hazard. The Timberman 58(7):50–52.

Clar, C. Raymond.
1959. California government and forestry—from Spanish days until creation of the Department of Natural Resources in 1927. Calif. Div. For., Sacramento, 623 p.

Clar, C. Raymond.
1969. California government and forestry during the Young and Ralph administrations. Calif. Div. For., Sacramento, 319 p.

Cook, Wayne R.
1966. Slash disposal by chippers. Fire Control Notes 27(2):7.

Corbett, Edward S., and Raymond M. Rice.
1966. Soil slippage increased by brush conversion. USDA For. Serv. Res. Note PSW-128, 8 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Cornelius, Donald R., and N. W. Talbot.
1955. Rangeland improvement through seeding and weed control on east slope Sierra Nevada and southern Cascade mountains. U.S. Dep. Agric., Agric. Handb. 88, 51 p.

Countryman, Clive M., and Charles W. Philpot.
1970. Physical characteristics of chamise as a wildland fuel. USDA For. Serv. Res. Pap. PSW-66, 16 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Crafts, Alden S.
1955. General contact weed killers. Calif. Agric. Exp. Stn. Circ. 447, 16 p.

Cramer, Owen P.
1968. Comments on "What is air quality and how is it influenced by the burning of forest fuels?" *In* Prescribed burning and management of air quality—a seminar, Tucson, Ariz., p. 29–31.

Darley, E. F., F. R. Burleson, E. H. Mateer, and others.
1966. Contribution of burning agricultural wastes to photochemical air pollution. Air Pollut. Control Assoc. J. 16(12):685–690.

Davis, Edwin A., and Charles P. Pase.
1969. Selective control of brush on chaparral watersheds with soil-applied fenuron and picloram. USDA For. Serv. Res. Note RM-140, 4 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Davis, Gary G., Lawrence E. Bartel, and C. Wayne Cook.
1975. Control of gambel oak sprouts by goats. J. Range Manage. 28(3):216–218.

Davis, James B.
1971. Diammonium phosphate prevents roadside fires. Fire Control Notes 32(1):7–9.

Davis, Lawrence S.
1965. The economics of wildfire protection with emphasis on fuel-break systems. Calif. Div. For., Sacramento. 166 p.

Day, Maurice W.
1965. Cacodylic acid as a silvicide. Quart. Bull. Mich. Agric. Exp. Stn. 47(3):383–386.

DeBano, Leonard F.
1969. Water repellent soils: a worldwide concern in management of soil and vegetation. Agric. Sci. Rev. 7(2):11–18.

DeBano, L. F., and R. M. Rice.
1973. Water-repellent soils: their implications in forestry. J. For. 71(4):220–223.

Deeming, John E., James W. Lancaster, Michael A. Fosberg, R. William Furman, and Mark J. Schroeder.
1972. The National Fire Danger Rating System. USDA For. Serv. Res. Pap. RM-84, 165 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Dell, John D., and Franklin R. Ward.
1969. Reducing fire hazard in ponderosa pine thinning slash by mechanical crushing. USDA For. Serv. Res. Pap. PSW-57, 9 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Dixon, Merlin J.
1965. A guide to fire by prescription. USDA For. Serv. South. Reg., Atlanta, Ga. 33 p.

Dodge, Marvin.
1972. Forest fuel accumulation—a growing problem. Science 177(4044):139–142.

Dodge, Marvin, and Cecil Pierce.
1962. Anchor chain improves brush rangeland. Calif. Div. For. Range Improv. Stud. 7, 8 p., Sacramento.

Dunham, R. S.
1965. Herbicide manual for noncropland weeds. U.S. Dep. Agric., Agric. Handb. 269. 90 p.

Eckert, Richard E., Jr., and Raymond A. Evans.
1967. A chemical-fallow technique for control of downy brome and establishment of perennial grasses on rangeland. J. Range Manage. 20(1):35–41.

Edmunson, George C., and Donald R. Cornelius.
1961. Ryegrasses for southern California fuel-breaks. USDA For. Serv. Res. Note 186, 6 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Elam, F. Leland.
1952. Goats cleared our brush. West. Livestock J. 30(42):37,46,51,55.
Evanko, A. B.
[n.d.] Manipulation of brush cover on California National Forests. USDA For. Serv., Calif. Reg., San Francisco. 70 p.
Evans, Raymond A., Richard E. Eckert, Jr., and Burgess L. Kay.
1967. Wheatgrass establishment with paraquat and tillage on downy brome ranges. Weeds 15(1):50–55.
Flynn, E. Loree.
1973. California's Angora goat. Calif. Livestock News 47(4):4–11.
Fons, W. L.
1946. Analysis of fire spread in light forest fuels. J. Agric. Res. 72:93–121.
Forman, O. L., and D. W. Longacre.
1970. Fire potential increased by weed killers. Fire Control Notes 31(3):11–12.
Friedman, J., and Y. Waisel.
1966. The influence of wind velocity and fuel density on the burning of litter of *Pinus halepensis* and *Tamarix aphylla*. La-Yaaran 16(2):81, 93–94. [also, Biol. Abstr. 28(3):3986, July 1967.]
Fuel-Break Executive Committee.
1963. Guidelines for fuel-breaks in southern California. Fuel-Break Rep. 9, 25 p. USDA For. Serv. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.
Furbush, Paul.
1953. Control of medusahead on California range. J. For. 51(2):118–121.
Gantz, R. L., and E. R. Laning, Jr.
1963. Tordon—for the control of woody rangeland species in the Western United States. Down to Earth 19(3):10–13.
Gilbert, Richard, and Jef Schmidt.
1970. Ball and chain crushing. Calif. Div. For. Range Improv. Stud. 19, 8 p. Sacramento.
Goodin, J. R., L. R. Green, and V. W. Brown.
1966. Picloram—a promising herbicide for control of woody plants. Calif. Agric. 20(2):10–12.
Gratkowski, H.
1968. Repeated spraying to control southwest Oregon brush species. USDA For. Serv. Res. Pap. PNW-59, 6 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.
Green, Lisle R.
1970. An experimental prescribed burn to reduce fuel hazard in chaparral. USDA For. Serv. Res. Note PSW-216, 6 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.
Green, L. R., G. C. Edmunson, D. R. Cornelius, and A. B. Evanko.
1963. Seeding fuel-break areas in southern California. Fuel-Break Rep. 10, 18 p. USDA For. Serv. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.
Green, Lisle R., and Joe R. Goodin.
1965. A trial of picloram for controlling chaparral species in southern California. West. Weed Control Conf. Proc. 20:28–30.
Green, Lisle R., Joe R. Goodin, and T. R. Plumb.
1966. Picloram herbicide for killing chaparral species—a preliminary rating. USDA For. Serv. Res. Note PSW-122, 8 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.
Green, Lisle R., and Harry E. Schimke.
1971. Guides for fuel-breaks in the Sierra Nevada mixed-conifer type. 14 p. USDA For. Serv. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.
Green, L. R., K. A. Wagnon, and J. R. Bentley.
1958. Diet and grazing habits of steers on foothill range fertilized with sulfur. J. Range Manage. 11(5):221–227.
Green, L. R., V. E. White, and T. R. Plumb.
1963. Some brush conversion costs on southern California fuel-breaks. Fuel-Break Rep. 12, 18 p. USDA For. Serv. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.
Hall, J. Alfred.
1972. Forest fuels, prescribed fire, and air quality. 44 p. USDA For. Serv. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.
Hanes, Ted L.
1965. Ecological studies on two closely related chaparral shrubs in southern California. Ecol. Monogr. 35(Spring):213–235.
Harvey, W. A.
1958. The history of chemicals in weed control. Calif. Farm Bur. Mon. 39(8):22–23.
Harvey, W. A.
1971. Effects of weed control on the environment. 23rd Annu. Calif. Weed Conf. Proc., Sacramento, p. 68–74.
Heirman, Alan L., and Henry A. Wright.
1973. Fire in medium fuels of west Texas. J. Range Manage. 26(5):331–335.
Hellmers, Henry.
196?. The San Gabriel mountains. Eng. and Sci. Mag., Calif. Inst. Tech. 7 p.
Hoffman, Garlyn O., and Robert H. Haas.
1969. Controlling drift of herbicidal sprays. Fact Sheet L-848. 4 p. Texas A & M Univ. Agric. Ext. Serv., College Station.
Hoglund, Oswald K.
1948. Seed dilution with rice hulls. Pleasanton Nursery Unit. Proc. 1 p. U.S. Dep. Agric., Soil Conserv. Serv., Pleasanton, Calif.
Holloway, J. K.
1964. Projects in biological control of weeds. p. 650–670. *In* Biological control of insect pests and weeds. P. DeBach and E. I. Schlinger, eds. Reinhold Publ. Corp., New York.
Horton, J. S., and C. J. Kraebel.
1955. Development of vegetation after fire in the chamise chaparral of southern California. Ecology 36(2):244–262.
Huffaker, C. B., and C. E. Kennett.
1959. A ten-year study of vegetational changes associated with biological control of Klamath weed. J. Range Manage. 12(2):69–82.
Huss, Donald L.
1971. The use of goats as a brush control adjunct in northern Mexico. Abstr. of papers, 24th Annu. Meet., Soc. Range Manage., Reno, Nev. 13 p.
Huss, Donald L.
1972. Goat response to use of shrubs as forage. *In* Wildland shrubs—their biology and utilization. USDA For. Serv. Gen. Tech. Rep. INT-1. p. 331–338. Intermt. For. and Range Exp. Stn., Ogden, Utah.
Ilch, D. M.
1952. Some limitations on the use of succulents for erosion control. J. Soil and Water Conserv. 7:174–176, 196.
Jones, Milton B., and Horton M. Laude.
1960. Relationships between sprouting in chamise and the physiological condition of the plant. J. Range Manage. 13(4):210–214.
Kay, Burgess L.
1966. Paraquat for range seeding without cultivation. Calif. Agric. 20(10):2–4.
Kay, Burgess L., and Cyrus M. McKell.
1963. Preemergence herbicides as an aid in seeding annual rangelands. Weeds 11(4):260–264.
Kay, Burgess L., and Richard E. Owen.
1970. Paraquat for range seeding in cismontane California. Weed Sci. 18(2):238–244.
Kilgore, Bruce M., and George S. Briggs.
1972. Restoring fire to high elevation forests in California. J. For. 70(5):266–271.
King, N. K., and R. G. Vines.
1969. Variation in the flammability of the leaves of some Australian forest species. CSIRO, Div. Appl. Chem., Melbourne, Australia. 14 p.

Kirch, J. H.
1967. The formulation and application of herbicides. *In* Symposium: herbicides and vegetation management in forests, ranges, and noncropland. Div. Contin. Educ., Oreg. State Univ., September 7–9, p. 67–71.
Kollander, Harry R., Harold Weaver, and Edward M. Gaines.
1955. Additional information on prescribed burning in virgin ponderosa pine in Arizona. J. For. 53(10):730–731.
Koller, Dove, and M. Negbi.
1959. The regulation of germination in *Oryzopsis milaceae*. Ecology 40(1):20–36.
Lange, A., B. Fischer, W. Humphrey, W. Seyman, and K. Baghott.
1968. Herbicide residues in California agricultural soils. Calif. Agric. 22(8):2–4.
Laude, Horton M., Milton B. Jones, and William E. Moon.
1961. Annual variability in indicators of sprouting potential in chamise. J. Range Manage. 14(6):323–326.
Lemon, Paul E. and A. L. Hafenrichter.
1947. The dilution method for plot or field seeding of grasses and legumes alone or in mixtures. J. Am. Soc. Agron. 39:817–821.
Leonard, O. A.
1960. Repeated applications of herbicides to live oak sprouts essential for complete kills. Calif. Agric. 14(1):15.
Leonard, O. A.
1967. How plant physiology affects weed control under Mediterranean conditions. Agrichem. West 10(9):14, 16.
Leonard, O. A., and C. E. Carlson.
1958. Chamise control with aircraft. Calif. Agric. 12(4):9,12.
Leonard, O. A., and C. E. Carlson.
1959. Aircraft spraying of blue oak. Calif. Agric. 13(12):2.
Leonard, O. A., and W. A. Harvey.
1965. Chemical control of woody plants. Calif. Agric. Exp. Stn. Bull. 812. 26 p.
Lindenmuth, A. W., Jr., and James R. Davis.
1973. Predicting fire spread in Arizona's oak chaparral. USDA For. Serv. Res. Pap. RM-101, 11 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
Martin, J. P., and J. O. Ervin.
1970. Decomposition and transformation of herbicides in soils. 22nd Annu. Calif. Weed Conf. Proc., Anaheim, p. 83–108.
McKell, C. M., and B. L. Kay.
1964. Chemical fallow aids perennial grass establishment. Calif. Agric. 18(2):14–15.
McKell, Cyrus M., Vernon Stoutemeyer, Chester Perry, and others.
1966. Hillside clearing and revegetation of fire hazard areas. Calif. Agric. 20(12):8–12.
McKell, Cyrus M., Alma M. Wilson, and B. L. Kay.
1962. Effective burning of rangelands infested with medusahead. Weeds 10(2):125–131.
Miller, H. W.
1962. Cucamonga brome and Wimmera *62* ryegrass. Plant Materials Tech. Note 22. 2 p. U.S. Dep. Agric., Soil Conserv. Serv., Pleasanton, Calif.
Montgomery, Marvin L., and Logan A. Norris.
1970. A preliminary evaluation of the hazards of 2,4,5-T in the forest environment. USDA For. Serv. Res. Note PNW-116, 11 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.
Murphy, Alfred H., R. Merton Love, and Lester J. Berry.
1954. Improving Klamath weed ranges. Calif. Agric. Exp. Stn. Circ. 437, 16 p.
Murphy, J. L.
1963. Conflagration barriers—a new concept. West. For. Conserv. Assoc. Annu. Meet. Proc., Portland, Oreg., p. 10–12.
Murphy, James L.
1965. An analysis of the economic efficiency of an experiment in conflagration control on the Stanislaus National Forest, California. Ph.D. diss., Univ. of Mich., Ann Arbor. 275 p.
Murphy, James L., Lisle R. Green, and Jay R. Bentley.
1967. Fuel-breaks—effective aids, not cure-alls. Fire Control Notes 28(1):4–5.
Murphy, James L., and Harry E. Schimke.
1965. Tests of an experimental slash ignition unit. USDA For. Serv. Res. Note PSW-69, 3 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.
Mutch, Robert W.
1967. Cheatgrass coloration—a key to flammability. J. Range. Manage. 20(4):259–260.
Nord, Eamor C., Donald R. Christensen, and A. Perry Plummer.
1969. *Atriplex* species (or taxa) that spread by root sprouts, stem layers, and by seed. Ecology 50(2):324–326.
Nord E. C. and J. R. Goodin.
1970. Rooting cuttings of shrub species for California wildland plantings. USDA For. Serv. Res. Note PSW-213, 4 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.
Oliver, William W.
1970. Cacodylic acid for precommercial thinning on mixed-conifer stands shows erratic results. USDA For. Serv. Res. Note PSW-224, 3 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.
Pacific Northwest Forest and Range Experiment Station.
1971. PNW Annual Report. USDA For. Serv., Portland, Oreg. p. 17.
Pase, Charles P.
1971. Effect of a February burn on Lehmann lovegrass. J. Range Manage. 24(6):454–456.
Pase, Charles P., and A. W. Lindenmuth, Jr.
1971. Effect of prescribed fire on vegetation and sediment in oak–mountain mahogany chaparral. J. For. 69(11):800–805.
Perry, P. W., and R. P. Upchurch.
1968. Growth analysis of red maple and white ash seedlings treated with eight herbicides. Weed Sci. 16(1):32–37.
Phillips, Clinton B., Louis E. Gunter, Grant E. McClellan, and Eamor C. Nord.
1972. Creeping sage—a slow burning plant useful for fire hazard reduction. Fire Control Notes 26. 8 p., Sacramento.
Philpot, C. W.
1970. Influence of mineral content on the pyrolysis of plant materials. For. Sci. 16(4):461–471.
Pirsko, Arthur R., and Lisle R. Green.
1967. Record low fuel moisture follows drought in southern California. J. For. 65(9):642–643.
Plumb, T. R.
1961. Sprouting of chaparral by December after a wildfire in July. USDA For. Serv. Tech. Pap. 57, 12 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.
Plumb, T. R.
1962a. Four tests of broadcast spraying in killing first-year chamise sprouts. USDA For. Serv. Res. Note PSW-200, 6 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.
Plumb, T. R.
1962b. Three years of broadcast spraying chamise sprouts in southern California. USDA For. Serv. Res. Note 197, 9 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.
Plumb, T. R.
1963. Delayed sprouting of scrub oak after a fire. USDA For. Serv. Res. Note PSW-1, 4 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.
Plumb, T. R.
1968. Control of brush regrowth in southern California with Tordon and phenoxy herbicides. Down to Earth 24(3):19–22.
Plumb, T. R.
1969. Control of chamise regrowth with phenoxy herbicides—affected by sprout age, date of application. USDA For. Serv. Res. Note PSW-192, 5 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.
Plumb, T. R.
1971. Broadcast applications of herbicides to control scrub oak regrowth. USDA For. Serv. Res. Note PSW-261, 4 p. Pac.

Southwest For. and Range Exp. Stn., Berkeley, Calif.
Plumb, T. R., and J. R. Bentley.
1960. Rate of broadcast 2,4-D spraying on second-year chamise sprouts. USDA For. Serv. Res. Note PSW-163, 7 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.
Plumb, T. R., J. R. Bentley, and V. E. White.
1963. Chemical control of brush regrowth on fuel-breaks. Fuel-Break Rep. 11, 41 p. USDA For. Serv. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.
Plumb, T. R., L. R. Green, and V. E. White.
1966. Spray pattern and drift from two types of nozzles used for helicopter spraying. Weeds 14(2):114–116.
Range Seeding Equipment Committee, Chemical Plant Control Subcommittee.
1966. Chemical control of range weeds. U.S. Dep. Agric. and U.S. Dep. Int., Washington, D.C. 39 p.
Rice, R. M.
1963. It's not over when the fire's out. 4 p. USDA For. Serv. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.
Rice, R. M., E. S. Corbett, and R. G. Bailey.
1969. Soil slips related to vegetation, topography, and soil in southern California. Water Resour. Res. 5(3):647–659.
Rice, R. M., and G. T. Foggin III.
1971. Effect of high intensity storms on soil slippage on mountainous watersheds in southern California. Water Resour. Res. 7(6):1485–1496.
Roby, George A., and Lisle R. Green.
1976. Mechanical methods of chaparral modification. U.S. Dep. Agric., Agric. Handb. 487. 46 p.
Ryker, Russell A.
1966. Herbicides fail to insure success of a brushfield prescribed burn. USDA For. Serv. Res. Note INT-55, 7 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.
Sampson, Arthur W.
1944. Plant succession on burned chaparral lands in northern California. Calif. Agric. Exp. Stn. Bull. 685. 144 p.
Sampson, Arthur W., and L. T. Burcham.
1954. Costs and returns of controlled brush burning for range improvement in northern California. Calif. Div. For., Sacramento. 41 p.
Schimke, Harry.
1963. Tests of a wind machine as an aid to burning slash. USDA For. Serv. Res. Note PSW-37, 5 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.
Schimke, Harry E.
1965. Chipping of thinning slash on fuel-breaks. USDA For. Serv. Res. Note PSW-58, 4 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.
Schimke, Harry E., John D. Dell, and Franklin R. Ward.
1969. Electrical ignition for prescribed burning. 14 p. USDA For. Serv. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.
Schimke, Harry E., and Ronald H. Dougherty.
1966a. A petroleum gel as a slash ignition aid and fuel booster. USDA For. Serv. Res. Note PSW-97, 5 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.
Schimke, Harry E., and Ronald H. Dougherty.
1966b. Disposal of logging slash, thinnings, and brush by burying. USDA For. Serv. Res. Note PSW-111, 4 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.
Schimke, Harry E., and Ronald H. Dougherty.
1967a. Coating green slash—asphalt and wax prevent drying. USDA For. Serv. Res. Note PSW-143, 2 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.
Schimke, Harry E., and Ronald H. Dougherty.
1967b. Disposing of slash, brush, and debris in a machine loaded burner. Fire Control Notes 28(3):7–9.
Schimke, Harry E., and Lisle R. Green.
1970. Prescribed fire for maintaining fuel-breaks in the central Sierra Nevada. 9 p. USDA For. Serv. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.
Schimke, Harry E., Lisle R. Green, and Danny Heavilin.
1970. Perennial grasses reduce woody plant seedlings . . . on mixed conifer fuel-break. USDA For. Serv. Res. Note PSW-203, 4 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.
Schimke, Harry E., and James L. Murphy.
1966. Protective coatings of asphalt and wax emulsions for better slash burning. Fire Control Notes 27(2):5–6, 15.
Schroeder, Mark J., and Charles C. Buck.
1970. Fire weather—a guide for application of meteorological information to forest fire control operations. U.S. Dep. Agric., Agric. Handb. 360. 229 p.
Schuft, Peter H.
1972. A prescribed burning program for Sequoia and Kings Canyon National Parks. Tall Timbers Fire Ecol. Conf. Proc. 12:377–389.
Schultz, A. M., and H. H. Biswell.
1953. Reseeding burned rangeland. Calif. Agric. 7(3):3–4.
Scifres, C. J.
1972. Herbicide interactions in control of sand shinnery oak. J. Range Manage. 25(5):386–389.
Scifres, C. J., and G. O. Hoffman.
1972. Comparative susceptibility of honey mesquite to dicamba and 2,4,5-T. J. Range Manage. 25(2):143–146.
Sinclair, J. D.
1954. Erosion in the San Gabriel mountains of California. Trans. Am. Geophys. Union 35(2):264–268.
Sterling, Theodor D.
1971. Difficulty of evaluating the toxicity and teratogenicity of 2,4,5-T from existing animal experiments. Science 174:1358–1359.
Stinsen, Kenneth J., and Henry A. Wright.
1969. Temperatures of headfires in the southern mixed prairie of Texas. J. Range Manage. 22(3):169–174.
Sweeney, James R.
1956. University of California publications. Botany 28:143–250.
Tschirley, Fred H.
1968. Response of tropical and subtropical woody plants to chemical treatments. U.S. Dep. Agric., Agric. Res. Serv., Crops Res. Div., Res. Rep. CR13–67. 197 p.
Uggla, E.
1958. Skogsbrandfalt I Muddus National Park. Acta Phytogeogr. Suec. 41:5–116.
Upchurch, R. P., J. A. Keaton, and F. L. Selman.
1968. Soil sterilization properties of monuron, diuron, simazine, and isocil. Weed Sci. 16(3):358–364.
Upchurch, Robert P., and Robert L. Merz.
1967. The preparation of oil soluble formulations of pentachlorophenol and the evaluation of their defoliant/desiccant action on Ilex and Privet. Final Rep., Agric. Res. Dep. Monsanto Co., St. Louis, Mo. [For U.S. Army Contract DAAA-13-67-C-0138, Fort Detrick, Md.]
U.S. Department of Agriculture.
1955. Typical waterholding characteristics of different-textured soils. *In* Water. U.S. Dep. Agric., Yearb. Agric. p. 120.
U.S. Department of Agriculture.
1965. Controlling honey mesquite. Agric. Res. 14(4):3–4.
U.S. Department of Agriculture, Forest Service.
1972. Report of close timber utilization committee. 73 p.
U.S. Department of Agriculture, Forest Service.
1957. Project Fuel-Break. 3 p. California Forest and Range Exp. Stn., Berkeley, Calif.
U.S. Department of Agriculture, Forest Service— California Region.
1956. Fire problems affecting basic protection of California National Forests. San Francisco. 18 p.
U.S. Department of Agriculture, Forest Service—California Region.

[n.d.] Fuel-breaks—planning treatment. 7 p. San Francisco.
U.S. Department of Agriculture, Forest Service—California Region.
1959. Pre-attack—planning and construction guide for forest fire suppression. 66 p. San Francisco.
Vlamis, J., and K. P. Gowans.
1961. Availability of nitrogen, phosphorus, and sulfur after brush burning. J. Range Manage. 14(1):38–40.
Wagle, Robert Fay.
1955. The foliage desiccation effects of various chemical mixtures on five southern California brush species. Master's thesis, Univ. of Wash., Seattle. 103 p.
Wagnon, Kenneth A.
1963. Behavior of beef cows on a California range. Calif. Agric. Exp. Stn. Bull. 799. 58 p.
Weaver, Harold
1952. A preliminary report on prescribed burning in virgin ponderosa pine. J. For. 50(9):662–667.
Weaver, Harold.
1967. Some effects of prescribed burning on the Coyote Creek test area—Colville Indian Reservation. J. For. 65(8):552–558.
Weed Society of America.
1967. Herbicide handbook. W. F. Humphrey Press, Geneva, N. Y. 293 p.
Whalley, R. Derwyn B., Cyrus M. McKell, and Lisle R. Green.
1966. Seedling vigor and the early nonphotosynthetic stage of seedling growth in grasses. Crop Sci. 6(March-April):147–150.
White, Verdie E., and Lisle R. Green.
1967. Fuel-breaks in southern California, 1958–1965. 33 p. USDA For. Serv. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.
Wilson, A. D.
1969. A review of browse in the nutrition of grazing animals. J. Range Manage. 22(1):23–28.
Zivnuska, John A.
1972. Economic tradeoffs in fire management. *In* Fire in the environment symposium Proceedings, Denver, Colo., May 1–15. U.S. Dep. Agric., For. Serv., FS-276. [Published in cooperation with Can. and Mex.]

☆U.S. GOVERNMENT PRINTING OFFICE: 1977 O—218-572