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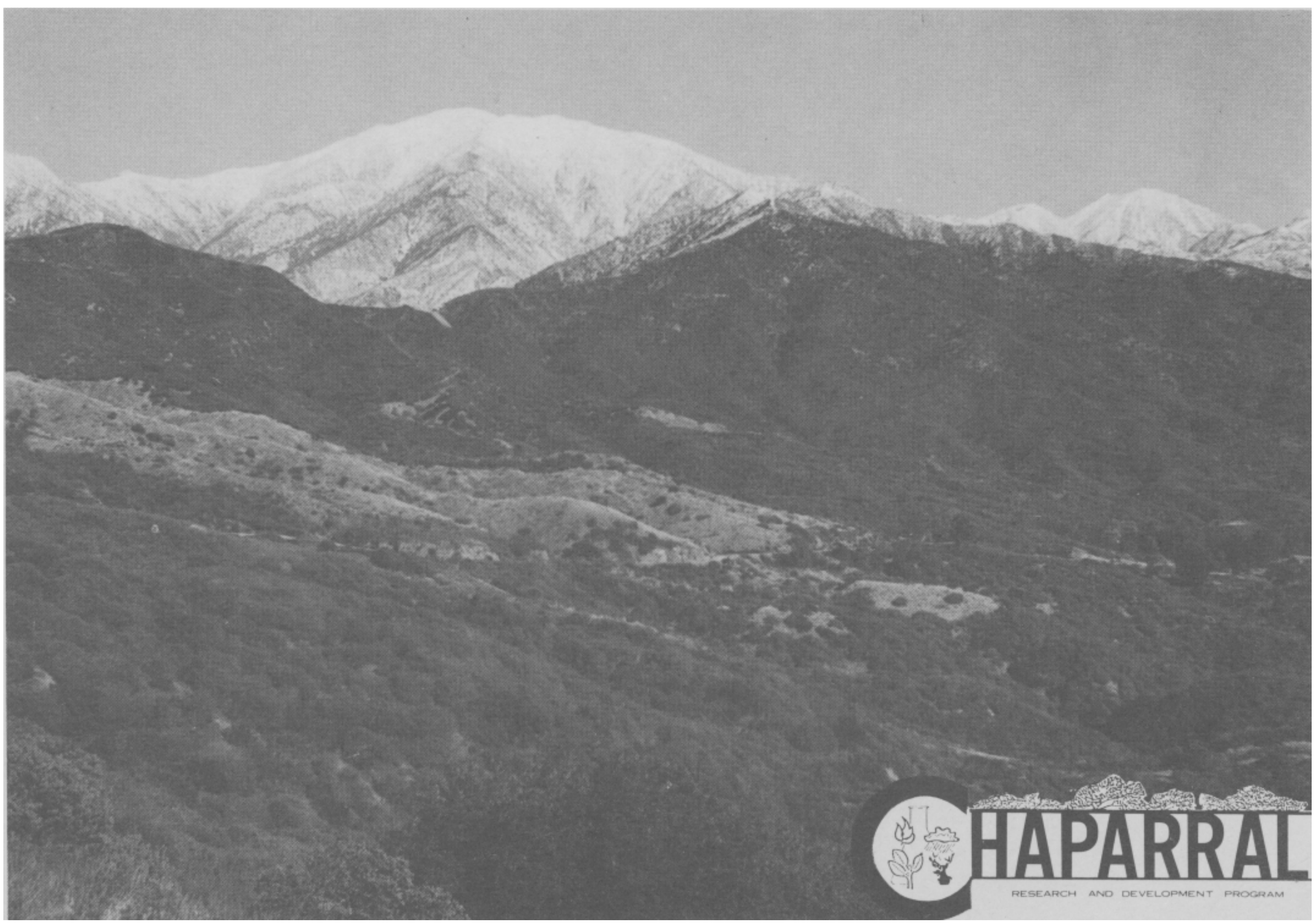
Chaparral and Associated Ecosystems Management: a 5-year research and development program

C. Eugene Conrad George A. Roby Serena C. Hunter



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INTRODUCTION

Chaparral—evergreen, sclerophyllous shrubs with associated ecosystems of grass, sage scrub, broadleaved and conifer plant communities—is the dominant vegetative type in the wildlands of central and southern California. Until recently, chaparral was considered of little value, and management strategy focused mainly on fire suppression. But this rapid suppression of fires under moderate weather and fuel conditions over the years has resulted in a heavy buildup of fuels in large areas. Under hot, dry, windy conditions, these heavy fuels become large, uncontrollable fires, setting the stage for larger fires in the future. In the wildland-urban interface, homes and other improvements are often lost in these conflagrations.

The continuation of large, disastrous wildfires, despite large-scale suppression efforts, led resource managers to implement new fire and vegetation management methods. Also, the growing awareness of the value of chaparral for purposes of watershed, wildlife habitat, recreation, livestock grazing, and potential energy production suggested a prescription for change. Until then, chaparral vegetation generally had been viewed as worthless, good for little more than fuel for wildfire. But attitudes began to change. Managers were encouraging the search for tools and techniques that could enhance these resources.

This increased awareness in the value of chaparral and associated ecosystems led to the establishment of the Chaparral Program. In 1976, the Pacific Southwest Forest and Range Experiment Station and the Pacific Southwest Region, Forest Service, U.S. Department of Agriculture, began a 5-year research and development program: Vegetation Management Alternatives for Chaparral and Related Ecosystems. Headquartered at Riverside, California, the program was designed as a framework for chaparral-related research and to accelerate the development of urgently needed management techniques. The program's charter specified research with brush-type vegetation as well as woodlands and certain conifer forests.

This report provides a nontechnical overview of the program's accomplishments. It summarizes the program's intensive efforts of technology development and transfer to diverse user groups, and describes the changing management philosophy throughout the program. This report bears special importance for managers and landowners in planning and implementing efficient land management policies related to chaparral and associated ecosystems.

CHAPARRAL AND ASSOCIATED ECOSYSTEMS

California chaparral communities range from 500 to 3000 feet (150 to 900 m) elevation in the north and from 1000 to 5000 feet (300 to 1500 m) elevation in the south. Associated vegetative types grow adjacent to chaparral—above it, below it, or intermingled with it, as along drainages. Typical chaparral species include chamise *(Adenostoma fasciculatum)*, scrub oak *(Quercus dumosa)*, several manzanita species (*Arctostaphylos* spp.), and several ceanothus species (*Ceanothus* spp.) (Conrad 1985). Usually, chaparral species begin to grow in midwinter in southern California and in late winter in northern California. Growth continues until early summer in most years. Associated woodlands, often dominated by oak trees and several conifer species, begin growth later than chaparral and continue growing later into summer. Woodlands with better soil moisture availability also produce more herbaceous undergrowth than chaparral (Hunter 1982b, Paysen 1982, Paysen and others 1982).

The sage scrub vegetative type commonly associated with chaparral—often called soft chaparral—is dominated by drought-deciduous, semiwoody shrubs, and frequently has a herbaceous component. The semiwoody shrubs species include sage (*Salvia* spp.), sagebrush *(Artemisia californica)*, buckwheat *(Eriogonum fasciculatum)*, and brittlebush (*Encelia* spp.). Each year, several component species produce more aromatic compounds than most chaparral shrubs, as well as a significant quantity of semiherbaceous or at least soft woody material. This semiherbaceous growth annually matures, much of it dying back to a more hardened woody component. Above-normal precipitation—especially if during the growing season of important sage scrub species—results in above-normal growth of the semiherbaceous parts of plants. As a result, the species produces dead material in above-normal amounts due to this above-normal rainfall and growth. The typical sage scrub type is associated with low-elevation chaparral which pervades to sea level. Annual growth often begins with the onset of significant fall or winter rains and ceases soon after the last rainfall in spring. Chaparral and woodlands are associated with the moister, cooler margins of sage scrub. Grasslands are another vegetative type often found adjacent to sage scrub. Usually, however, it is difficult—if not impossible—to identify clear and consistent ecosystem properties to explain the shift from sage scrub to grassland.

Fire and Plant Community Relationships

Chaparral, sage scrub, and associated herbaceous plants adapt to harsh environmental conditions. They can tolerate extended summer drought, poor soils, unstable slopes, and desiccating winds. The plants have been especially successful in adapting to fire. In fact, periodic burning is integral to the life cycle of chaparral communities (Hunter 1981, Radtke and others 1982).

Chaparral and associated ecosystem vegetation have adapted to fire in two major ways: (1) These species have mechanisms of regenerating successfully after a fire by quickly sending up sprouts from the root collar or by fire-stimulated germination of seeds; and (2) they have various chemical, physical, and physiological characteristics that tend to make them flammable. These characteristics ensure that old, nonproductive stands burn readily, making way for vigorous regeneration (Philpot 1979, 1980).

The tendency for chaparral vegetation to burn presents a problem for land managers, mainly since more than 10 million people live or work within chaparral areas or benefit from watershed values and recreation provided by these wildlands. Historically, wildfires—and the flooding and erosion that often follow—have cost dearly in terms of life and property. Therefore, any management strategy must account for the relationship between chaparral ecosystems and fire.

When heavy fuels dominate large areas, wildfires frequently burn on extensive flaming fronts for long distances. When old stands of chaparral and associates, including accumulated dead material, intermingle with or are adjacent to even more flammable sage scrub plant communities, fire can grow at remarkably uneven rates. Fire tends to move more rapidly on south-facing slopes where the vegetation is likely to be sage scrub or chamise chaparral, and the air temperature and humidity are more extreme.

Commodity Resource Potential

A chief aim of the Chaparral Program was to protect lives and reduce property loss rather than to improve forest biomass yield. Chaparral and associated ecosystems probably have no significant potential for economically producing commercial biomass on a large scale. Water, on the other hand, is of significant value. About one-third of the water demand, about 1 million acre-feet (28,000 m^3) of usable water, is obtained from this source each year by the Metropolitan Water District of southern California. Most of this water, which is stored in underground basins of southern California, originates from upland sources.

Converting shrub and tree stands to vegetation that demands less water results in a higher water yield. But the excess erosion from increased water yield often outweighs the benefits. On the San Dimas Experimental Forest in Los Angeles County, a steep watershed that was converted to grass in 1961 produced 2 ¼times more sediment after conversion (Wells 1982a). Therefore, a major value of forests, woodlands, and shrublands is to provide watershed stability and ensure maximum delivery of potable water to underground storage.

Benefits less tangible than water also derive from chaparral and associated ecosystems, including aesthetic, recreational, and wildlife values (Hunter 1982). Another benefit, though difficult to measure, is the ability of vegetation to use carbon dioxide and even some chemicals considered pollutants to produce biomass (Conrad 1982, Riggan and Dunn 1982). Many managers and landowners realize that these indirect benefits are significant but require a better understanding of fundamental ecosystem processes.

THE CHAPARRAL PROGRAM

To implement the Chaparral Program, an extensive survey was conducted to assess user suggestions and needs. Workshops focused on areas of concern to researchers and practitioners from the Forest Service and cooperating agencies and universities. Managers and researchers were an especially valuable resource during the assessment phase. Significant needs of the program were also addressed at an international symposium, Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems (Mooney and Conrad 1977), held at Stanford University, in August 1977. Program personnel became informed and acquainted with field managers through field trips. For example, a tour of the 130,000-acre Laguna-Morena Demonstration Area in San Diego County, California, in April 1977, clarified much of the program's intent. The area subsequently became the site of most program demonstrations.

Some research supported by the program leaned strongly toward understanding basic chaparral processes, since data available from sound fundamental research were scant. At the beginning of the program, knowledge in some areas was insufficient for high-quality applied research in chaparral or woodland ecology. The physiology of fire on oak and other woodland species were, for the most part, unknown and currently remain only slightly studied. Existing research showed that several chaparral species were capable of symbiotic nitrogen fixation, but the nature and occurrence of those processes remained elusive. Moreover, we continue to have only broad, untested theories to explain the relationships among oak, conifer, and chaparral ecosystems. As a result of the program, however, the complexities of these associated ecosystems are better understood.

User groups contributed substantially to the program's resources by developing technology, publishing research findings and user guides, participating in training and demonstrations, as well as reporting program activities. For example, a team developed the Vegetation Classification System (Paysen and others 1980). Its members were from the California Department of Fish and Game, Southern California Edison Company, as well as National Forests. Substantial research was sponsored by the program through cooperative agreement with universities. Such research has benefitted both public and other public and private land resources in the southwestern United States, the Mediterranean basin, and countries such as Australia, Chile, Mexico, and South Africa.

RESEARCH AND DEVELOPMENT

Understanding Chaparral Ecosystems

Management of chaparral ecosystems is complicated: the components of the ecosystems are constantly changing. Soil on steep, unstable slopes is subject to gravitational movement that is aggravated by fire, rain, wind, and animal activity. The stages of succession cause distinct shifts in plant species following fire or other disturbance. In turn, nutrient cycles and wildlife populations fluctuate with the fire cycle and successional changes in vegetation. Also, physiological changes in vegetation occur with age, seasonal changes in temperature, and water availability.

Understanding the interrelationship of these mutable processes is requisite to effective chaparral management. The Chaparral Program sponsored several studies that focused on the dynamics of the chaparral ecosystem. These studies included vegetation classification, water-repellent soils, hydrology and sediment relationships, nutrient cycling, physiological relationships, and photo-oxidant effects.

Vegetation Classification

A Vegetation Classification System was designed for California (Paysen 1983; Paysen and others 1980, 1982). The system is compatible with the vegetation elements of the Component Land Classification for the United States, developed by the Resources Evaluation Techniques Program, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado, and the international system for classifying vegetation. The Vegetation Classification System represents the efforts of a multiorganizational group. Consequently, the resulting system has applicability over a broad area, as evidenced in its adoption by the State of Hawaii as a framework for its own resource inventory and vegetation system.

The Vegetation Classification System is designed to aid all disciplines in natural resource management *(fig. 1)* (Hunter and Paysen 1982). Earlier systems were usually oriented to a specific discipline so that every specialist—ecologist, wildlife biologist, forester, or range manager—required a different classification system. This system provides a standardized vegetation classification procedure and nomenclature, and includes a flexible category for data germane to a specific user. As a result, the system provides a universal language that responds to diverse needs.

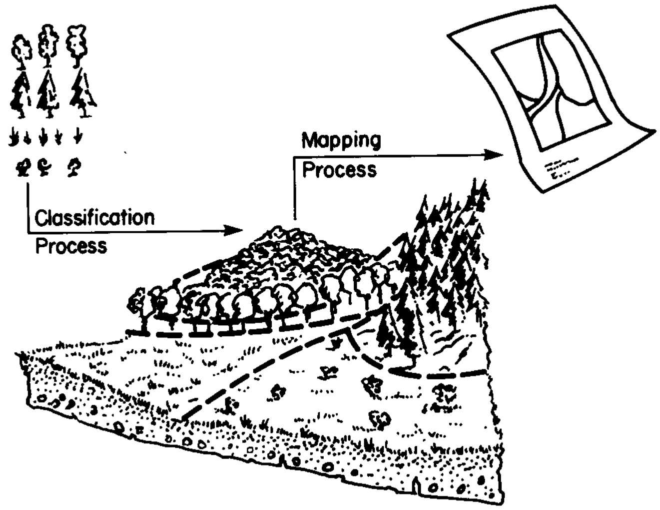

Figure 1—Classification of vegetation in areas of chaparral and associated ecosystems should precede other land management activities such as mapping.

Plant communities reflect the composition of their environment—rainfall, soil, and fire, for example. Most managers and biologists accept this. That no clear demarcation separates one plant community from another, however, often causes disagreement. The distribution of sage scrub, chamise chaparral, and mixed chaparral plant communities is related to rainfall *(fig. 2)*. Sage scrub is a common vegetative type typically associated with chamise chaparral. Of 1622 systematic grid map locations in southern California (excluding deserts), 1118 were in these three communities. Of these, 560 locations were in chamise chaparral, 200 in mixed chaparral, and 358 in sage scrub. The other 504 locations were in six additional vegetative types. Both sage scrub and chamise

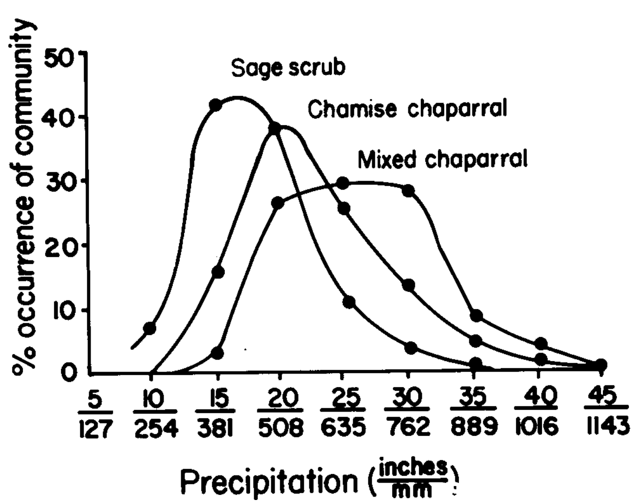

Figure 2—Three associated shrub communities as a percent of 1622 observations in the southern California non-desert zones.

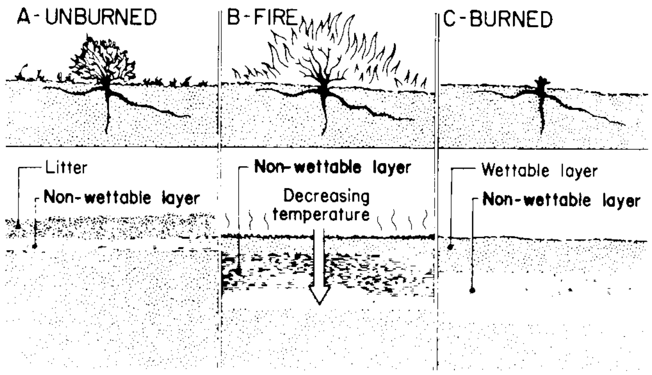

Figure 3—The general theory for the formation of a water-repellent soil layer with fire includes volitalizing chemicals present in a moderately repellent layer by heat, then condensing these water repelling chemicals on soil particles in a more concentrated layer.

chaparral have well-defined peak occurrences at about 16 and 21 inches of precipitation. Mixed chaparral is almost equally abundant in the 20- to 30-inch precipitation range (Conrad and Paysen 1979).

Water-Repellent Soils

Chaparral fires can cause some soils to become water repellent or hydrophobic. The present theory explaining how hydrophobic soils are formed is shown graphically in *figure 3*. The mechanism of hydrophobic soil formation has been explained and identified as important to postfire sediment yields (DeBano and others 1977, 1979). Work sponsored by the Chaparral Program showed the extent to which hydrophobic conditions occur and their effect on nutrient transport from site. One state-of-the-art report (DeBano 1981) discussed the nature of water-repellent soils, kinds of water-repellent substances, effects of soil-water repellency on water movement, fire-induced soil-water repellency, management problems and implications of water repellency, and research needs.

Studies begun during the Chaparral Program have continued, focusing on decomposition rates in hard-to-wet soil layers and the role of these layers in erosion processes such as rill formation. Such research is part of a series of hydrologic studies that identify how the relationships between fire, water-repellent soil, soil texture change, and erosion can be predicted in managing chaparral lands (Wells 1981, 1982a; Dunn and others 1982).

Hydrology and Sediment Relationships

When the Chaparral Program started, little information was available on debris movement as related to fire occurrence and behavior, hydrologic events, and land treatments. Yet this cause-and-effect information was necessary for managers to choose land treatment alternatives such as prescribed burning or seeding of grasses.

A comprehensive sediment model that included all southern California watersheds was a major contribution. The model was produced by the program in cooperation with the California Institute of Technology (Brown and Taylor 1982, Brownlie and Taylor 1981, Kolker 1982, Taylor and Brownlie 1982, Wells and Brown 1982, Wells and Palmer 1982). This model shows that erosion on steep chaparral slopes is best described as an episodic process strongly influenced by complex internal thresholds. The unpredictable response of these slopes to eroding forces is due to the thresholds. Soil movement is a direct result of fire and postfire conditions (Duriscoe and Wells 1982; Fall 1981; Tiedemann and others 1979; Wells 1981, 1982a).

A major change in understanding soil erosion in chaparral areas is attributable to Chaparral Program research. Previously, all erosion was considered undesirable. This attitude stemmed from experience with agricultural lands where rich topsoil is a valuable resource and erosion reverses the natural depositional process. But on steep, naturally unstable chaparral slopes, undemanding ecosystems have developed mechanisms for adequately replacing or foregoing lost nutrients. In the chaparral ecosystem, erosion is natural, and in the long term unpreventable. The real management issues created by erosion are flooding and sedimentation that occur in populated valleys below (Nat. Acad. Sciences 1982, Taylor and Brownlie 1982, Wells 1982b, Wells and Brown 1982, Wells and Palmer 1982).

Nutrient Cycling

Nutrient cycling in chaparral ecosystems was a major target of Chaparral Program research. Little was known about this subject before the program began. Both the chemical and biochemical aspects of nutrient cycling were investigated with emphasis on nitrogen loss and replacement, especially after fire. We learned that the effect of fire on nutrients is limited chiefly to the volatilization of nitrogen and, to a lesser degree, potassium. In addition, small quantities of all nutrients may be transported on windblown particles and smoke (DeBano and Conrad 1976, 1977; Dunn and Debano 1977; Dunn and Poth 1979; Riggan 1979; Wells and others 1979).

A common conclusion is that erosion by water is responsible for large postfire losses of all nutrients; certainly, a large amount of surface soil is lost (Kolker 1982; Wells 1981, 1982b). Soil particles removed by erosion carry some of all nutrients (DeBano and Conrad 1976, 1977; DeBano and Dunn 1982). A major reason for prescribed fire, therefore, is to reduce nutrient loss by reducing fire-related erosion (DeBano and Dunn 1982).

Nitrogen merits special consideration, since it is easily volatilized by heat and must be replenished after fire. Also, it is the absence of this nutrient that most likely limits plant growth. Data are now available that quantify nitrogen loss during and after fires of varying intensity from soils of varying moisture content. Managers can use these data to reduce nitrogen loss or estimate tradeoffs when considering prescribed burning (DeBano and Conrad 1977).

Some mechanisms by which nitrogen is recovered or replaced have been identified. Nitrogen-fixing legumes such as lupine (*Lupinus* spp.) and deerweed (*Lotus* spp.), nonleguminous plants such as California lilac (*Ceanothus* spp.), as well as nitrogen-fixing organisms have been investigated, but the extent of their roles is less certain. Also, all nitrogen replacement observed on chaparral sites cannot be attributed by the above cures, based on current measurement techniques (Poth 1980, 1982; Poth and Dunn 1982; Riggan and Lopez 1982).

The interrelationships among soil microorganisms, heating rates associated with wildfires or prescribed burns, soil moisture at the time of a fire, and various nitrogen-fixing plant species have been studied, but much remains to be learned about the dynamics of nutrients in chaparral systems. Little is understood about the transfer of nitrogen and other nutrients through the ecosystem from the rooting zone into stream water, the role of *Ceanothus* spp. in postfire nitrogen replacement, and how nitrogen replacement varies by parent material, fire intensity, existing vegetation, and species of microorganism (Dunn 1980; Dunn and Reynolds 1979; Mishler 1978).

Despite many unanswered questions, substantial information of value to chaparral land managers has resulted from the Chaparral Program.

Physiological Relationships of Chaparral Species

Program scientists and cooperators investigated several areas related to the physiology of chaparral plant species. Studies focused on how plants vary by species, age, and season in their water-use patterns, photosynthesis and carbon metabolism, growth patterns, and response to fire. Understanding these variables is requisite to evaluating the effects of prescribed burning, biomass harvesting, herbicides, and other management tools practiced within the chaparral community.

Data on photosynthetic rates and plant water status for several important chaparral species were developed through cooperative research with the Systems Ecology Group, at San Diego State University (Hastings and Oechel 1982, Lawrence and Oechel 1982, Oechel and Lawrence 1979, Oechel and others 1981, Oechel and Mustafa 1979). Photosynthetic rates, which depend largely on sunlight, carbon dioxide, water, and certain trace minerals, indicate the effectiveness of the plant to accumulate energy and carbon for growth, reproduction, and buildup of reserves. Species with relatively high photosynthetic rates generally have high ground cover and competitive advantage over species with lower rates. Management techniques that alter the relative photosynthetic rates among species may also alter the species composition of the affected community (Oechel 1982).

Photosynthesis varies not only by species, but by season, elevation, slope, plant moisture status, and age as well. During the first months after fire, maximum photosynthetic rates by resprouts were observed at rates several times greater than for mature plants. Yet resprouts in a hand-cleared area had photosynthetic rates similar to those observed in mature plants (Hastings and Oechel 1982, Oechel and Hastings 1983). These findings suggest that chaparral stands may not be able to rally after repeated biomass harvesting in the same way that they respond to periodic burning. Nevertheless, current information on biomass accumulation after harvesting remains scant (Oechel 1982).

The response of various oak species to fire was investigated (Plumb 1980a, 1980b; Plumb and McDonald 1981). Species were rated according to their fire tolerance. Also, variables thought to affect fire tolerance—bark surface texture and thickness, age, trunk diameter, and crown height—were studied. Based on this research, the chances for postfire recovery of an oak—given the species, size, and degree of charring—can now be predicted. A guide to postfire treatment of oak stands has been developed (Plumb 1980b, Plumb and Gomez 1983). Acorn production management was also studied, including the timing and methods for collecting, storing, and germination (Plumb 1981, 1982).

Photo-oxidant Effects

Air pollution—a force largely caused by humans—influences the dynamics of chaparral and associated ecosystems. The Los Angeles Basin, for example, is subject to high levels of air pollution due to its topography, meteorological characteristics, and high population density. The smog drifts east and intensifies as it reaches higher elevations in the San Bernardino Mountains *(fig. 4)*. The Chaparral Program, in cooperation with the University of California and Environmental Protection Agency, sponsored research to determine the effects of airborne pollutants on plant communities, concentrating specifically on the conifer forests of the San Bernardino Mountains where pollution damage has been severe (Axelrod and others 1980, James and others 1980, Miller and Erdman 1977, Miller and others 1982, Miller and Kickert 1985, Miller and others 1979, Miller and White 1977, Winer and others 1981).

Research efforts focused mainly on the pollutant ozone (O_3), the primary component of smog that damages plants. Symptoms were identified and guides developed for identifying the extent and severity of ozone damage to trees. The relative sensitivities of native and frequently planted tree species were determined. As a result, the most sensitive species are now known: ponderosa pine, Jeffrey pine, western white pine, and the Jeffrey-Coulter pine hybrid (Miller 1980a, 1980b, 1983a, 1983b; Miller and others 1978,1980; Miller and Van Doren 1982).

Chaparral shrubs are relatively insensitive to airborne pollutants. In a study of susceptibility of several common chaparral species to ozone injury, seedlings developed more symptoms of injury than mature plants (Stolte 1982). Also, the

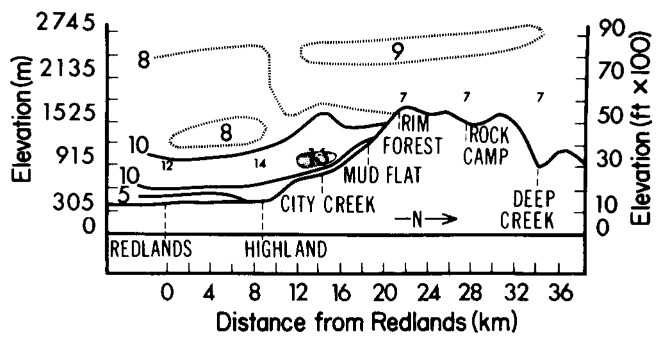

Figure 4—Concentration of oxidant air pollutants in parts per hundred million at 9:00 A.M. on a typical smoggy day in the San Bernardino Mountains of southern California.

severity of injury was negatively correlated with the amount of thick and leathery leaf characteristics developed. Because leaves of seedlings are softer (more mesophyllous) than leaves of mature plants, damage is more severe. With regard to seedlings, chaparral whitethorn *(Ceanothus leucodermis)* was most severely damaged, followed by chamise *(Adenostoma fasciculatum),* bigberry manzanita *(Arctostaphylos glauca),* and scrub oak *(Quercus dumosa).* On the other hand, chaparral whitethorn was the only mature chaparral plant that showed cause for concern due to susceptibility to dosage levels in its habitat range.

Some air pollution effects on plant communities may be positive. By acting as a sink for airborne chemicals, trees and shrubs may conserve the chemicals and convert them to plant biomass rather than allowing them to be exported in percolated water to streams (as in grasslands). Future studies should emphasize both the positive and negative interactions of air pollution with nonpollution-related environmental stresses. These interacting forces may well favor some species, thereby influencing forest succession and management practices.

Managing Chaparral Ecosystems

Pursuing an understanding of chaparral is important for managers of chaparral and associated ecosystems. The preceding discussion has shown that these ecosystems are dynamic and complicated. But managers must also deal with factors other than chaparral ecology. The complex interactions between man and nature are recognized worldwide. Hunter (1982a) found that management objectives related to Mediterranean-type ecosystems were surprisingly similar worldwide. The objectives most often mentioned by international experts are grazing, recreation, watershed protection, aesthetics, and nature conservation. Of recurring significance in achieving those objectives is fire and fuel technology. This is nowhere more apparent than in southern California.

Prescribed Burning

Planned burning of chaparral fuels is not new. California ranchers have been burning for range improvement under permit from the California Department of Forestry since 1945. Burning for human benefit has a much longer history in California, but records do not include how early fires were planned. Even so, the idea of burning chaparral fuels on public land was still rather bold and controversial when the Chaparral Program began. Many recognized the potential value of fire for achieving resource objectives related to fire-hazard reduction, range improvement, sediment and flood management, and wildlife habitat. The focus centered on safety and containment of large-scale burning in highly flammable vegetation such as chaparral. Few managers in the Pacific Southwest Region were experienced in prescribed burning. Moreover, few experienced in fire suppression felt confident that they could plan and carry out a prescribed burn.

A comprehensive report on prescribed burning and predicting burn results was compiled for land managers (Green 1981). This guide and parts which were released serially helped to introduce safe and productive prescribed fire practices on public lands in California. Although much remains to be learned, much is now known about fire behavior and its effects in relation to diverse weather conditions, plant species, fuel moisture and age, season, and aspect. Most important, chaparral land managers are now armed with the basic information required to use prescribed burning as an operational tool (Green 1978, 1980, 1982; Hunter and Philpot 1982; Dougherty and Riggan 1982).

The moisture content of living chaparral fuels is one of the more significant variables when predicting fire behavior. To standardize the determination of fuel moisture content, procedures were developed for both field sampling and laboratory analyses (Countryman and Dean 1979, McCreight 1981). This method of monitoring changes in fuel moisture content was adopted in a statewide system of permanent sampling plots set up by the Forest Service and the California Department of Forestry (Countryman and Bradshaw 1980). Resource managers now use this method to assess live fuel moisture on specific sites for which prescribed burns are planned.

The helitorch is one of the most significant tools developed for prescribed burning since the program was started. It was first tried in California brushfields on the Mendocino National Forest in 1979 (Bungarz 1982). Since then it has become almost indispensable. Burning globs of jellied gasoline drop from a torch slung a safe distance below the helicopter *(fig. 5)*. The flaming globs of jellied gasoline fall through the brush and ignite dead material under the green canopy. With the helitorch, brush can be burned when it contains more moisture, fire can be laid onto almost any spot in the brushfield, and ignition can be completed quickly or slowly, depending on the prescription. An expert helitorch pilot can lay fire on a precise perimeter line or a ground crew can set the perimeter fire and the helitorch can then build a hot interior fire that drafts the fire into the project area.

Several experimental burns were planned cooperatively between National Forests and the Chaparral Program, each contributing significantly to assessing preburn preparation, worker requirements, and equipment needs. For some experimental burns, data such as fire behavior and intensity, soil moisture, and season of burn were recorded and extrapolated to postfire conditions such as soil effects, successional patterns, and sediment production (DeBano and Conrad 1976, DeBano and Conrad 1977, DeBano and others 1977, Dunn and DeBano 1977). Four burns on the Cleveland National Forest (Dougherty and Riggan 1982) as well as a series of test burns on the Los Padres National Forest and other southern California forests contributed to our prescribed burning procedures.

A few understory burns were prescribed beneath mixed-conifer or oak canopies. Based on these experimental burns and the known sensitivity of specific oak species to fire (Plumb 1980b), prescriptions for underburning have been

Figure 5—The helitorch drops flaming globules of jellied gasoline that carries fire through the brush igniting dry sticks and leaves.

recommended (Green 1980, 1981). These prescriptions, however, are considered preliminary and need further testing and refinement.

Other Fuel Management Techniques

Although prescribed fire received the most attention from the Chaparral Program, other fuel management techniques were examined. These procedures included mechanical equipment, hand labor, and herbicides (Bentley and Estes 1978; Green 1977a, 1977b, 1978; Hield and others 1984; Plumb and Goodin 1982; Plumb and others 1977; Roby and Green 1976). An assessment of biological methods focused on the use of browsing animals, in this case goats, for brush control.

Goats best serve in controlling young regrowth, such as brush on cleared fuelbreaks. Although goats eat a greater variety of plants than other livestock species (Green and others 1978; Green and Newell 1982; Sidahmed 1981; Sidahmed and others 1981, 1982), they become increasingly selective as the shrubs age. Goats should not be expected to control tall, mature brush, but they provide a promising alternative to herbicides for controlling brush regrowth (Green and others 1978). Goats pose specific problems in chaparral: the need for roads, fencing or herding, water, and supplemental feeding. They must also be protected from predators, disease, and poisonous plants. A comprehensive survey on goat control of regrowth is available (Green 1982).

One fuel management approach investigated early in the program was the planting of low-volume and slow-burning vegetation on clearings such as fuelbreaks. Since the 1940's, the search for such plants has been sporadic. Test plantings revealed about 20 shrubs and an equal number of grasses that showed promise for planting on brush-cleared areas (Nord and Green 1977). But collecting seeds and propagating and establishing plants on harsh wildland sites have proven large-scale planting to be impractical. However, many species studied are used for home landscaping in wildland areas (Radtke 1981, 1982, 1983).

Managing for Wildlife

Chaparral management techniques diversely affect wildlife and wildlife habitat (Quinn 1982). The scant data on chaparral ecosystem fauna makes it difficult to properly assess the impact of management plans on wildlife. Cooperating university scientists have reviewed and evaluated available information on chaparral mammals (Bayless 1980; Quinn 1979a, 1979b; Wirtz 1977), insects (Force 1979), birds (Alten 1981; Dutton 1981; Wirtz 1979a, 1979b), and reptiles (Simovich 1979).

The abundance and diversity of wildlife in California's chaparral is not commonly recognized. Chaparral habitat supports about 49 species of mammals alone (Quinn 1979b). During a 2-year period, 85 species of birds were observed in burned and unburned grassland and chaparral areas on the San Dimas Experimental Forest (Wirtz I979a). In a larger scale study on the San Dimas Experimental Forest and adjacent areas, 128 species of birds representing 36 families were documented. Ninety-nine of the bird species were at 3000 to 4200 feet (900 to 1300 m), the mid-elevation zone of chaparral and associated plant communities; 110 species were sighted at 4600 feet (1400 m) (Wirtz 1979b, 1982). Flower-attracted insects, especially bees, are more abundant and species-rich in chaparral than in any other California vegetation and are responsible for most pollination (Force 1979).

The effects of wildfire and prescribed fire upon chaparral wildlife were of special interest to the program. By altering the structure and composition of the plant community, fire in chaparral can profoundly affect the animal community. Fortunately, these changes in the plant and animal communities are normally temporary. Nevertheless, it is of value to know the fluctuation patterns of various animal communities as they relate to the fire cycle and to plant succession. It is also of value to know how fire frequency, intensity, and size affect animal communities. Postfire succession of birds (Alten 1981, Wirtz 1979a), reptiles (Simovich 1979), mammals (Quinn 1979a, Wirtz 1977), and insects (Force 1982) has been studied. Currently, information suggests that, in general, wildlife habitat may be optimized by maintaining chaparral in many age classes, by restricting the size of burned or treated areas, by protecting trees, and by enhancing water sources (Quinn 1979b).

A wildlife habitat guide is in preparation by National Forest cooperators that comprehensively describes the mammal, reptile, and bird species currently inhabiting California's chaparral (Loe and Kenney 1985). The guide will comprehensively review the literature and include data on distribution, special habitat requirements, territory requirements, and breeding and feeding habitats. A map of specific bird sightings will be included.

Managing Woodlands and Riparian Zones

Interest in actively managing woodland and riparian zones in California is increasing. In most of California, the highest current values of these zones are for wildlife habitat, watershed protection, recreational and aesthetic character, and some livestock grazing; but they also contain a large reservoir of fuel and fiber. Woodland and riparian species commonly intermingle along drainages or other moister areas within chaparral zones and require special management considerations due to their high value.

By defining management options, the Chaparral Program emphasized the significance of woodland management. A regional symposium—the first of its kind—was sponsored in 1979 that brought together researchers and managers interested in the ecology, management, and utilization of California oaks (Plumb 1980a). Chaparral Program researchers contributed on oak inventory and distribution records (Paysen 1980), the role of prescribed fire in oak management (Green 1980), nutrient-microbial considerations (Dunn 1980), damage to oaks by fire (Plumb I980b), and air pollution effects on California black oak (Miller and others 1980).

Oak regeneration received some attention from Chaparral Program researchers. Acorn storage techniques, germination rates, and planting techniques were studied (Hunter and Van Doren 1982, Plumb 1981, Plumb 1982, Plumb and McDonald 1981). Results suggested that viable scrub oak *(Quercus dumosa)* acorns can be picked 1½ to 2 months before normal drop, but the tip of the pericarp must be removed on these immature acorns to obtain satisfactory germination. Pericarp removal is unnecessary in mature acorns. Cold stratification increased germination percentages for early collections of California black oak *(Q. kelloggii)*, canyon live oak *(Q. chrysolepis)*, and interior live oak *(Q. wislizenii)* (Plumb 1982).

Substantial tree-to-tree differences in germination percentage and rate were found for acorns collected from California black oak and coast live oak *(Q. agrifolia)* mother trees. Average moisture content of acorns at the time of collection ranged from 37 to 66 percent for mother trees of California black oak and from 45 to 65 percent for mother trees of coast live oak. In general, germination was poorer for acorns with higher moisture contents (Hunter and Van Doren 1982).

Continuing Fire Problems

In spite of attempts to prevent fire and manage fuel, wildfire and to some extent large-scale conflagrations will continue in California's chaparral region. This is inevitable due to the climate and flammability of chaparral vegetation. Successful suppression during this century has undoubtedly contributed to fuel buildups that result in large, intense wildfires. Major fires in California have a history that antedates the arrival of Europeans, occurring an average of once every 65 years in the coastal area near Santa Barbara and once every 30 to 35 years further inland (Byrne 1979, Byrne and others 1977). Evidence of fossil charcoal and pollen from layered (varved) sediments from the floor of the Santa Barbara Channel discredits the theory that prehistoric wildfires in this area were frequent, low-intensity events. On the contrary, it indicates that conflagrations were common, especially in coastal areas.

In recent decades, interest in chaparral fire has increased due to the effects on people. The population of southern California has grown rapidly. Homes and buildings push the borders of the wildlands. Areas that a few years ago would have caused little concern if threatened by fire now harbor residential communities and isolated homes as well. One objective of the Chaparral Program was to apprise residents in this wildland-urban interface of the fire and watershed problems associated with these areas. Two in-depth reports were addressed to wildland managers, developers, land use planners, zoning agencies, and interested lay public (Radtke 1982, 1983). Both publications discuss the fire-flood-erosion cycle, sound building designs and locations relative to topography, home landscaping for fire and watershed safety, and actions to take when a house is threatened by fire.

An analysis of west coast wildfire hazard and prevention showed that some communities deal with these problems more effectively than others (Lee 1980, 1982). The analysis pressed for studies involving a cross-section of California, Oregon, and Washington counties. These studies would examine previous exposure to wildfire, the number of organizations in each county dedicated to fire hazard and prevention, and the extent to which community organizations or operations are responsive to fire issues. An analysis was also urged of existing precautionary measures to wildfire hazard in the wildland-urban interface. An analysis of the relationships of the variables would help to characterize communities that are more likely to adopt successful programs for managing interface fire hazards. The findings would give federal and state agencies an improved basis to cooperate more effectively and to allocate limited funds and technical assistance more efficiently.

INFORMATION AND TECHNOLOGY TRANSFER

Information and technology transfer from researchers to users and from one agency or land manager to another required the collection and interpretation of research and management experience. In turn, that information was made available to managers and landowners as an aid in developing their own management policies, objectives, and treatment techniques. The information also served scientists in formulating research analyses, objectives, funding requests, and studies.

Information distribution began immediately after the program was established. The Chaparral Program was given broad exposure through demonstrations, user guides, training and technical sessions, field trips, symposia, extension education, and consulting.

Extension Services

Demonstrations

Demonstrations were conducted primarily at the Laguna-Morena Demonstration Area, east of San Diego. The area includes land owned by several state and federal agencies and private landowners. The Cleveland National Forest is the largest landowner whose personnel were most active in the program. Vegetation treatment demonstrations included mechanical, chemical, biological (goat grazing), and prescribed fire methods. By concentrating on the demonstrations in one area, visitors could compare the results of various vegetation management techniques.

Prescribed fire demonstration participants included private landowners, as well as representatives from the Forest Service, California universities, all levels of State and civic units, and three U.S. Department of Interior agencies—National Park Service, Bureau of Land Management, and Bureau of Indian Affairs.

Training

Training sessions and technical workshops were conducted in vegetation classification, mapping, fuel moisture sampling, prescribed burning, oak management, chaparral management, and fire behavior. Program personnel also participated in training classes planned by cooperating agencies or groups. Some sessions, especially in prescribed burning, included hands-on field experience at local sites as far away as Marana, Arizona.

Field Trips

Field trips effectively exposed managers, cooperators, foreign visitors, and others to current research and management issues. Field trips were made to the Laguna-Morena Demonstration Area, the San Dimas Experimental Forest, or one of the National Forests, usually in conjunction with meetings, training sessions, or symposia. These trips were often conducted jointly with the National Forest System or other agencies such as the Los Angeles County Fire Department. Occasionally, field trips were conducted to apprise the cooperators of current Chaparral Program activities.

Consulting

The program provided consulting services similar to those provided by the University of California Extension. Consultants reviewed research proposals, wildlife management plans, and prescribed burning programs for national forests, national parks, and state parks. They served on several interdisciplinary multiagency teams to aid in developing forest management plans and to deal with special problems such as fire safety in the wildland-urban interface. The program staff presented papers at conferences and symposia supported by other organizations and served as guest lecturers at universities and training sessions. They chose a variety of forums—from Sierra Club meetings to public television—to discuss chaparral management and program goals.

Publications

User guides provide a means of disseminating information to a widespread audience. They serve as a quick and ready reference. The Chaparral Program published or supported the following user guides:

- Measuring moisture content in living chaparral (Countryman and Dean 1979)
- Fire behavior program for hand-held, programmable calculators (Bradshaw 1980, Bradshaw and Dean 1980)
- Vegetation classification system applied to southern California (Paysen and others 1980, Hunter and Paysen 1982)
- Identification and postfire management of California oaks (Plumb and Gomez 1983)
- Burning prescriptions for chaparral (Green 1981)
- Use of goats in managing chaparral (Green and Newell 1982)
- Living more safely in the chaparral-urban interface (Radtke 1982, 1983)
- Managing water-repellent soils (DeBano 1981)
- Wildlife-habitat relationships in chaparral (Loe and Keeney 1985)
- Identification of important southern California shrub species (Conrad 1985).

In addition to these publications, the program sponsored the CHAPS Newsletter. Ten issues of CHAPS went to press, each with a different management theme. The newsletter mailing list grew from 90 to about 550 during its 5-year history. The Agriculture Extension Service at the University of California, San Diego, agreed to continue the newsletter service.

Symposia

Symposia provide opportunities for exchange of ideas, exposure to diverse topics, presentation and critique of research, and a published reference of the proceedings.

The program cosponsored three international symposia and two regional symposia:

- International Symposium on the Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, August 1-5, 1977, Palo Alto, California (Mooney and Conrad 1977)

Table 1 —*Changes in policy and practice concerning chaparral and associated ecosystems during the Chaparral Research and Development Program, 1977-1982*

1977	1982
1. Federal and state agencies concerned with wildlands management express interest in vegetation and fuels management, but make only small-scale applications, with little or no activity in southern California.	1. Most agencies have full-scale training programs and actively use a variety of vegetation and fuels management techniques.
2. California Department of Water Resources has no plans for chaparral management to augment water supplies to the State Water Project.	2 California Department of Water Resources does feasibility study to augment water supplies through chaparral management at Oroville, Thomes-Newville, and Castaic reservoirs; works with California Department of Forestry on statewide watershed analysis for similar management.
3. Most land management agencies lack active prescribed burning programs in California. All brushlands receive limited treatment herbicidally or mechanically. Active management of shrublands is rare due to high costs of alternatives.	3. Agencies become active as instigators and cooperators in statewide chaparral management projects on thousands of acres per year, with prescribed fire the major tool.
4. Bureau of Indian Affairs occasionally takes part in chaparral management projects on extensive land areas in the State.	4. Bureau of Indian Affairs is active in several areas. California Department of Forestry seeks ways to allow Chaparral Management Program on Indian lands within the State's area of fire protection responsibility.
5. Private landowners manage shrubland only where active Range Improvement Associations exist, primarily in Santa Barbara, Kern, and Shasta counties. High costs of mechanical methods and fear of liability from escaped prescribed fires are frequently cited as reasons for inaction by this group.	5. Private landowners respond to California Department of Forestry Chaparral Program in its first year with applications to treat 100,000 acres. Another 176,000 acres are projected for the second year. California Department of Forestry Range Improvement Program, projects treatment of 30,000 to 60,000 acres per year on private lands.
6. Land vegetated by chaparral species are considered worthless brushland by most managers and agencies.	6. Chaparral is viewed as a resource, such as for watershed, wildlife habitat, recreation, livestock grazing, and possible energy production. Agencies require that brushlands be managed for their resource values. Supplements are added to Forest Service manuals recognizing chaparral management.
7. Federal, state, and local agencies and landowners deal with brushlands independently, with little cooperation.	7. Strong cooperative effort prevails among organizations concerned with chaparral management, with many mutually compatible goals and objectives, and sharing of experience and knowledge.
8. Prescribed burning in chaparral is not large scale; therefore, specialized equipment and technology are lacking.	8. Equipment and technology (notably, the flying drip torch, or helitorch) is developed to increase size and safety of burns and decrease cost.
9. General public has little interest in, or knowledge of, prescribed burning.	9. Interest in prescribed burning is evidenced by articles in magazines such as *Arizona Highways, Omni, American Forests,* and *National Geographic.* Sierra Club and other conservation organizations express support for prescribed burning.
10. Research or management of woodland and riparian zones associated with chaparral is scant.	10. Woodland and riparian vegetation is often recognized and managed as a valuable resource. A California riparian systems symposium is held at Davis, California, in 1981.
11. Few chaparral researchers or managers have the opportunity to learn about similar ecosystems in other Mediterranean-type regions of the world.	11. International symposia in 1977 and 1981 increase awareness of researchers and managers to the international nature of many problems. Information exchange increases with program-sponsored study tour to Spain and France.
12. Homeowners in or adjacent to wildland areas are unaware of or inadequately informed of dangers associated with living in chaparral-urban interface.	12. Homeowner awareness of chaparral-urban interface problems increases, evidenced by neighborhood organizations that deal with watershed and fire hazards. Public demand for information is met by publications on how to deal with these problems.
13. All erosion and sediment movement in chaparral areas is viewed as undesirable. Preventative measures are always desirable.	13. Managers begin to recognize that erosion and fire are natural processes that characterize the commonly steep chaparral watersheds. Fire by prescription that allows limited erosion on a limited area is viewed as a sediment management tool.
14. Managers commonly view all fire as extremely detrimental to wildlife populations.	14. Managers become more aware of wildlife benefits from managed fire in chaparral and associated ecosystems. Managers begin to recognize that the effect on wildlife populations is generally beneficial, though the direct effects on individual organisms may be severe.

• Ecology, Management, and Utilization of California Oaks, June 26-28, 1979, Claremont, California (Plumb 1980a)

• Effects of Air Pollutants on Mediterranean and Temperate Forest Ecosystems, June 22-27, 1980, Riverside, California (Miller 1980a)

• Dynamics and Management of Mediterranean-Type Ecosystems: An International Symposium, June 22-26, 1981, San Diego, California (Conrad and Oechel 1982)

• Classification and Distribution of California Chaparral Ecosystems, December 28, 1979, Pomona, California.

CONCLUSIONS

Due to information and technology transfer, user attitudes and operations changed significantly during the 5-year Chaparral Research and Development Program *(table 1)*. The program developed, tested, and demonstrated vegetation management alternatives designed to maintain or enhance productivity of chaparral and associated ecosystems. In the interests of information and technology transfer, the program sponsored three international and two regional symposia; prepared user guides relevant to chaparral and associated ecosystems management; communicated with diverse user groups as well as agencies of the federal and state governments; provided extension services through demonstrations, training sessions, field trips, and consulting; and published proceedings of several symposia and reports on matters of chaparral management.

The changes affected by the program and its cooperators were timely. Interest in chaparral management was high and communication among managers and researchers was needed. Timing, skilled leadership, well-focused research, and participation of cooperators helped the program to achieve its goals.

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Chaparral is the dominant vegetation in the wildlands of central and southern California. It has evolved fire adaptions that make it flammable and trigger postfire regeneration, thereby ensuring plant community rejuvenation. To provide a framework for chaparral-related research and accelerate development and demonstration of urgently needed management techniques, the Forest Service, in 1976, began a 5-year research and development program. The Vegetation Management Alternatives for Chaparral and Related Ecosystems Program was organized by the Pacific Southwest Forest and Range Experiment Station and the Pacific Southwest Region, and headquartered at Riverside, California. This report provides a nontechnical overview of the program's 5-year accomplishments. The results should be useful to managers and landowners in planning and managing chaparral and associated ecosystems.

Retrieval Terms: chaparral, wildland management, prescribed fire, research and development, California