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Use of Ryegrass Seeding as an Emergency Revegetation Measure in Chaparral Ecosystems

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Cover: Ryegrass being sown by helicopter in a burned chaparral area.
(Photo courtesy of Los Angeles County Fire Department.)

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CONTENTS

IN BRIEF ...

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Fire is a common occurrence in the California chaparral. Aside from brush removal through combustion, physical changes also take place in the soil during fire. These changes lead to accelerated erosion rates which begin almost immediately and continue through the next 5 to 10 years (Rowe and others 1954; Wells and Brown 1982). Since the late 1940's seeding burned slopes with ryegrass for the purpose of quick revegetation and erosion reduction has been a common practice. It is generally easier and less expensive than mechanical means of dealing with the erosion problem.

However, ryegrass as well as other annuals require specific environmental conditions for good establishment to occur. Conditions thought to favor ryegrass and native annual plant establishment include gentle, well-spaced rains and mild temperatures. Timing and intensity of rainfall and temperature extremes, therefore, appear to have a significant impact on success of establishment (Blankenbaker and Ryan 1985; Conrad 1979; Corbett and Green 1965; Dodge 1979; Wakimoto 1979). In southern California, as well as in the foothills of the Sierra Nevada, it appears that the majority of rainfall precedes significant grass establishment in the first year after fire (Arndt 1979; Krammes and Hill 1963; Rice and others 1965).

Since rainfall patterns and temperature are highly correlated with geographic location, this, too, is an important factor to consider when the decision to seed is being made (Blanford and Gunter 1972; California Division of Forestry 1957-1972). Results of the limited number of studies available indicate establishment of ryegrass is much greater in northern and central California than in southern California.

The purpose of seeding ryegrass is to quickly achieve a vegetative cover on fire-denuded slopes. Studies comparing when ryegrass and native species emerge are limited. Schultz and others (1955) compared emergence of ryegrass and shrub seedlings and found ryegrass emerged 2 months earlier. To our knowledge, no studies have compared grass emergence with that of native annuals. Recent monitoring studies to look at grass and native species emergence have had limited success (Blankenbaker and Ryan 1985; San Bernardino National Forest 1981) due to poor grass establishment. Some research studies addressing the question have failed for the same reason (Corbett and Green 1965; Krammes and Hill 1963; Rice and others 1965).

It is known intuitively that vegetative cover decreases erosion, but few studies have linked measurements of ryegrass cover with measurements of erosion in a postfire chaparral environment, especially the first year. One problem in observing the effects of ryegrass on erosion is that erosion is so variable. Scott and Williams (1978) noted that side-by-side watersheds which were virtually identical in their soil and slope characteristics still showed 50 to 100 percent differences in erosion rates during major storms. Available experimental results give conflicting reports--with some indicating ryegrass cover reduces erosion (Corbett and Green 1965) while others indicate no effect (Krammes and Hill 1963). On chaparral slopes converted to grass, long-term increases in erosion have been observed (Bailey and Rice 1969; Corbett and Rice 1966).

A good establishment of grass cover on a seeded burn site may increase the volume of fine dead fuels by the end of the first growing season. The more fine dead fuels available, the more susceptible a fuelbed is to ignition. Thus, the chances of an early reburn may be increased (Nadkarni and Odion 1986; Wakimoto 1979; Zedler and others 1983).

By rapidly creating a mat of fibrous roots at the soil surface a good stand of ryegrass may inhibit the cotyledons of shrub seedlings from pushing through the soil to the light. This has been shown to reduce the chance of shrub seedlings from establishing (Keeley and others 1981; Schultz and Biswell 1952; Schultz and others 1955). Since chaparral seedlings establish primarily in the first 1 to 2 years postfire, future stand density and composition may be influenced by this early competition (Conrad 1979; Zedler and others 1983).

Through this literature survey, we have realized that there is a significant lack of information on the effects of fire on the chaparral ecosystem as well as the postfire recovery of chaparral areas after fire. Due to the incredible variability in erosion occurring in the field, it is difficult to conduct and pay for a study with large enough scope to answer the questions researchers and public agencies have on the effects of ryegrass seeding. We have outlined areas we feel are in need of further study. Substantial commitments of funds and personnel will be required to accomplish these aims.

INTRODUCTION

Although an integral component of chaparral ecosystems, fire causes substantial changes in soil and vegetative characteristics. After fire, rainfall of even low to moderate intensity can lead to dramatic episodes of flooding and erosion. At the urban-wildland interface, extensive property damage and high flood-control and cleanup costs may result. On the burn site itself, rainfall of intensity and amount that would have insignificant effects on unburned slopes can cause erosion and soil loss. This may result in significant site degradation through removal of enriched topsoil.

The societal costs of postfire erosion and flooding have increased as human settlements encroach on wildland areas. In an attempt to control or minimize these effects, public agencies have adopted the practice of seeding recently burned chaparral slopes with annual grasses (primarily ryegrass [*Lolium multiflorum*]). The efficacy of this practice in reducing erosion on burned chaparral slopes and possible long-term effects of introduced grasses on chaparral ecosystems are not known.

County, State, and Federal agencies with land management functions conduct most ryegrass seeding. Many forest management plans contain specific directives on what areas will be seeded, at what density, and when seeding will take place. Establishment of ryegrass on burned slopes is thought to stabilize the surface soil layers until native shrubs can establish themselves. The herbaceous plants sown on burned areas are intended to supplement the cover provided by naturally occurring postfire herbaceous vegetation.

Researchers and managers generally agree that seeded grasses decrease erosion only minimally the first postfire year. However, seeded grasses may have a greater impact the second and third years, when erosion rates will still be elevated from effects of fire. Any reduction in erosion can be equated with cost reductions in flood-related damage to structures and reservoir cleanouts.

Because homeowners view postfire seeding programs as an effort by land management agencies to protect both their property and the chaparral slopes, agencies are less likely to be found liable for damage to downstream property if efforts to stablilize [sic] slopes can be documented.

Many researchers (Conrad 1979; Gautier 1983; Nadkarni and Odion 1986; Rice 1975; Wakimoto 1979; Zedler and others 1983) are concerned that seeded ryegrass may not significantly reduce erosion and may lead to long-term changes in the chaparral ecosystem. Some evidence suggests that much of the postfire erosion occurs before seeded ryegrass can become established, and dense stands of ryegrass may inhibit establishment and growth of native chaparral shrubs (effectively leading to type conversion). Long-term erosion on slopes deliberately converted from brush to grass has been shown to exceed that on chaparral-covered slopes (Corbett and Rice 1966).

This report reviews current knowledge of the use of ryegrass seeding as an emergency revegetation measure in chaparral ecosystems. It describes the problem of accelerated erosion after wildfire; examines the constraints in establishment of ryegrass and native species; evaluates the role of ryegrass, native annuals and shrubs in reducing erosion; and postulates on how the introduction of ryegrass influences fuel characteristics and successional patterns of chaparral. Finally, it enumerates some limitations of past studies and makes recommendations for future research.

SEEDING PRACTICE

Early Use of Seeding

Flat land suitable for building was becoming scarce in the Los Angeles area by the late 1800's, and development began in areas adjacent to mountain watersheds. Fires that burned upstream watersheds often caused flooding and mudslides that destroyed these new developments. Major floods causing loss of life and extensive property damage occurred in 1914, 1934, and 1938 (Department of Forester and Fire Warden 1985). Foresters soon decided that preventive measures were necessary. They began to seed the slopes with species that would provide "early cover" in an effort to stabilize erosion-prone slopes and alleviate such disasters (Department of Forester and Fire Warden 1985).

The first species used for emergency revegetation were California native shrubs. Crews gathered seeds of *Ceanothus, Adenostoma fasciculatum* (chamise), *Aesculus californica* (buckeye), and *Heteromeles arbutifolia* (toyon); then, after fire, the native seeds were hand-sown on the burned slopes. The success rate for establishment of these shrubs was excellent, although the hand seeded natives emerged at the same time as the naturally seeded natives (Department of Forester and Fire Warden 1985).

Continued attempts to obtain early cover led to experiments with several introduced herbs. The earliest nonnative species used in emergency revegetation were species of mustard (*Brassica nigra, B. juncea,* and *B. alba*) seeded in the 1930's and 1940's (Archives 1919-1984, in Department of Forester and Fire Warden 1985). Mustard was selected because it was cheap, readily available, could be broadcast-seeded, had high viability, was easy to store and transport, and established itself quickly.

But, because the deep tap root did not hold surface soil layers well and seeds frequently washed down and established themselves as weeds in the fields and orchards below, the use of mustard species was soon discontinued (Colver 1986; Dodge 1979).

Many other native and introduced species were experimented with in the 1920's to 1940's. These included *Avena fatua* (wild oats), *Eriogonum fasciculatum* (buckwheat), *Lotus scoparius* (deerweed), *Spartium junceum* (Spanish broom), *Vicia* sp. (vetch), *Hordeum* sp. (barley), and *Bromus mollis* (blando brome) (Archives 1919-1984, in Department of Forester and Fire Warden 1985). *Lolium multiflorum* (Italian ryegrass), a native of temperate areas of Europe and Asia, was chosen in the late 1940's as the primary species to be used in reseeding efforts. Its fibrous root system appeared effective at stabilizing surface soil and, like mustard, it was available in large quantities, was inexpensive, could be broadcast seeded, and germinated quickly. The first aerial seeding of ryegrass occurred in December 1948 in the Verdugo Hills in Los Angeles County (Archives 1919-1984, in Department of Forester and Fire Warden 1985).

Vegetative Burn Rehabilitation Guidelines

Based on many years of operational experience, it became obvious that not all burned areas were good candidates for postfire seeding. In 1980, an interagency task force met to establish guidelines for reseeding burned watersheds (Thompson 1982). They came up with a set of criteria to determine where vegetative rehabilitation was needed and what site-specific measures should be taken. The first consideration is whether or not there are off-site or on-site values to be protected. If the answer is yes, the agency personnel can then proceed through physical, biological, and administrative considerations which need to be evaluated before the decision to revegetate is made.

The physical considerations are divided into four factors: soils, physiography, burn site characteristics, and climatic conditions. The soils are evaluated for their erosion hazard and potential for on-site losses. Slope, elevation, aspect, relief ratio, and stream length burned on the site are considered under physiography factors. Burn site characteristics that are evaluated include percent of the watershed burned, location of the burn in the watershed, channel loading, soil cover factor, and seedbed condition. Storm intensities and temperature regimes of a burned site are the climatic conditions considered.

All of these factors are associated with certain criteria levels on which the decision to seed or not seed will be based. For example, if only 0 to 20 percent of the watershed has been burned, seeding is low priority; if more than 40 percent has been burned, seeding is high priority. However, factors are considered together and not individually. A watershed that is only 0 to 20 percent burned may still be reseeded if other factors indicate a high risk.

The task force recognized biological considerations. They acknowledged the fact that chaparral vegetation is well-adapted to recover after fire without artificial revegetation. They also recognized that shrub species could be adversely effected by the successful establishment of a highly competitive grass. They state that "a treatment applied with good intentions to achieve short-term erosion-control benefits has the potential for producing adverse effects in the long-term stability of the chaparral"(Thompson 1982, p. 8).

Guidelines also recognize that adverse effects may be magnified by an early reburn of a successful reseeding effort. However, the overriding consideration in the decision to reseed is generally based on physical site characteristics and on social and economic factors (such as presence of downstream values).

Administrative procedures for decisions on what areas to seed include establishment of survey teams to evaluate damage, recommend treatment, and monitor seeded sites to determine the effectiveness of seeding.

Current Practice

Ryegrass is commonly sown at a density of 8 lbs/acre (9 kg/ha). This will give 80 percent vegetative cover if four ryegrass seeds/square foot (43 seeds/square meter) or 12.5 percent of the seed sown grow to maturity (Department of Forester and Fire Warden 1985). In the Los Angeles area of southern California after summer and early fall burns, seeding typically takes place in October. Late fall burns are seeded as soon as possible but no later than February 15. In the Los Padres National Forest in central California, seeding policies are similar (O'Hare 1986). The objective is to seed just before the winter rains but not so early that environmental factors (dry erosion, wind, and animals) operate to remove large numbers of seeds. Agencies attempt to seed before the first rain of the season so the ground surface will not be crusted. After later fires (September and October), slopes are seeded as soon as possible. Usually a minimum of 30 days is needed between the fire and seeding to set up seeding contracts (O'Hare 1986).

The cost of seeding in the 1980's may be as low as $2.00/acre ($5.00/ha) (Department of Forester and Fire Warden 1985) and go as high as $5.50-$7.00/acre (Wierman 1986a). The price is dependent on the size of the fire, the contractor, and the agency conducting the seeding. In general, the larger the fire, the lower the cost per acre. During the Wheeler fire in the Los Padres National Forest 118,000 acres (48,000 ha) were burned, and 73,000 acres (30,000 ha) were seeded. The cost breakdown per acre was as follows (Wierman 1986b):

	Cost	
	per acre	*per hectare*
Aerial application	$1.65	$4.07
Seed	$0.20	$0.48
Administrative cost	$0.22	$0.54
Total	$2.07	$5.09

ACCELERATED EROSION AFTER FIRE

Fire-Induced Changes

Rice (1974) calculated that in unburned chaparral a storm that moved significant amounts of sediment downstream could be expected to occur once every 8 to 10 years. After a fire, however, rainfall of normal to moderate intensity can produce dramatic episodes of downstream sediment movement. Fire appears to change the mechanical properties of surface soils, leading to increased erosion and severe floods. Three major mechanisms are thought to bring about these changes.

First, fire removes vegetative cover. This leads to a marked increase in dry-season sediment movement (dry ravel), which begins immediately after fire (Krammes 1960). Krammes noted that firefighters had to dodge large rocks moving downslope "only seconds after the fire passed." Removal of vegetative cover also makes the slopes especially vulnerable to erosion by rainsplash. According to Anderson and Trobitz (1949), density of the forest cover is a primary factor influencing sedimentation and peak flood discharges. Since denuded slopes are more vulnerable to erosion, the movement of sediments from the hillslopes to the channels is enhanced. Thus, material on the hillslopes and in the channels will be readily mobilized by the first significant precipitation.

Secondly, as soil is heated, combustion of organic particles may cause an increase in void (air) space between soil particles. This may reduce the soil shear resistance and lead to downhill movement of soil particles on steep slopes (Wells 1986). In steep topography, dry erosion caused by fire can charge ephemeral streams with large amounts of loose sediment that are mobilized during early postfire storms.

Thirdly, combustion of organic material during fire leads to formation of a water-repellant layer in the soil (DeBano 1981; Wells 1987). The water-repellant layer acts as a barrier to water penetration, reducing the hydrologically active mantle of soil from several feet to a few inches (Rice 1974). The soil's storage capacity being thus reduced, surface run-off is promoted. In addition, positive pore pressure in the soil above the water repellant layer appears to lead to liquefaction and numerous small-scale slope failures (Wells 1987). These slope failures initiate formation of a rill network that speeds the movement of debris from the burned slopes into the stream channels (Wells 1981).

Pre- and Postfire Sediment Production

In unburned chaparral stands, sliding of dry material down slopes is the predominant erosive process occurring in the San Gabriel Mountains (Doehring 1968; Scott and Williams 1978) as well as in the Ojai area and the Santa Clara River drainage (Scott and Williams 1978). Researchers in the San Gabriel Mountains (Anderson and others 1959; Krammes 1960) found that over half the annual erosion on unburned sites occurred as dry ravel. Rice (1974) estimated that 80 percent of the sediment leaving a chaparral watershed was derived from dry ravel and landslides.

Several studies have demonstrated large increases in sediment movement and flood peaks after fire. Krammes (1960) found that postfire dry-season erosion had increased to 8 to 34 times the prefire levels. On one burned site with steep, south facing slopes, 89 percent of the first year production of debris occurred as dry sediment movement within 88 days of the fire. Rice (1986) noted extremely rapid movement of dry material off the slopes after the 1960 Johnstone fire; he observed that debris cones blocked the roads in many areas within nine hours after the fire. Tom Ryan[1] has also established that surface sediment movement on burned plots was ten times that on unburned plots in the first year after fire. He used erosion troughs to monitor sediment movement in an experiment conducted in the Angeles National Forest.

In the San Dimas Experimental Forest (SDEF), where records of erosion and streamflow have been kept since the late 1930's, researchers were able to compare pre- and postfire erosion and flood peaks. Crouse and Hill (1962) examined peak flows during and after two comparable storms in two canyons. In one canyon, postfire peakflow increased to 200 times that of prefire levels. In an adjacent canyon, there was an 825-fold increase in flow after fire.

Wells (1984) compared sediment production from unburned watersheds to that of burned watersheds the first winter after fire. He found that sediment yielded from burned slopes after average precipitation events was comparable to that on unburned slopes after record precipitation events (> 8 in/hr or 20 cm/hr). The first year after fire, Hopkins and others (1961) noted that a 19-hour storm (which yielded less than 1 inch of precipitation) led to erosion rates 1.7 times greater than the annual prefire erosion rate.

The extent of postfire erosion is also indicated by the movement of seeds (with soil) from the hillslope and establishment of new vegetation in unusual areas after fire. Munns (1920) observed carpets of annuals on noneroded soils but very few herbaceous plants on eroded soils. Wells (1986) has noted lush vegetative growth on postfire deposits in stream channels.

Rowe and others (1954), after extensive surveys throughout coastal southern California, estimated that elevated erosion rates after fire did not return to prefire levels for 10 years. Wells and Brown (1982) believed that recovery occurred within 5 years (with over 95 percent of the increase in sediment occurring during this time). Narrowing this down even further, Wells (1984) estimated that 74 percent of the total sediment over a 22-year period was produced in the first 3 years after fire (from studies conducted in the mountains above Pasadena, California).

[1]Unpublished data on file, Pacific Southwest Forest and Range Experiment Station, Riverside, California.

In summary, fire-induced changes in the physical properties of soil and removal of vegetative cover by fire lead to large increases in both dry and wet erosion on burned slopes. The elevated levels of sediment production are most pronounced the first 3 years after fire-with the first year showing the greatest increase in comparison to prefire years. Dry erosion (dry ravel) contributes significantly to sediment production during fire, immediately after fire, and between fires, especially on the steep slopes in southern California. Large amounts of seed may also be moved off the bum site via erosive processes.

EMERGENCY REVEGETATION WITH SEEDED GRASSES

Meteorological Constraints on Establishment

On newly burned sites, high levels of available nutrients, increased availability of water and light, and removal of allelo-toxins favor the germination and establishment of herbaceous species. However, the success of establishment is tempered by factors such as rainfall patterns, timing and intensity; temperature; and wind.

Rainfall

In the foothills of California's Central Valley as well as the Coast Ranges, grass seeds typically germinate 5 to 7 days after the first winter rains of 0.5 to 1 inch (12.7 to 25.4 mm) (Bentley and Talbot 1951). In the foothills of the Sierra Nevada, germination may take a little longer (1-6 weeks after the first heavy rain, according to Schultz and others 1955). Rainfall that is well spaced and gentle without periods of intense rainfall or extended dry periods will favor significant growth (Rice and others 1965; Wakimoto 1979). Rice (1975) estimates that by early April (when 90 percent of the rainfall has occurred) the grass will have achieved 22 percent of its ultimate cover.

Temperature

Although ryegrass will germinate at temperatures below 50 °F (10 °C), significant growth does not occur until temperatures exceed 50 °F for several days in a row (Conrad 1979; Rice 1975). These conditions may not occur until the second half of February in southern California; above 2500 ft (762 m) on the SDEF, it is common for no growth to be visible until the first of March (Conrad 1979). In the foothills of the Sierra Nevada (central California), early growth of ryegrass is sporadic and slow. Frequently, leaf growth stops for several consecutive weeks during December, January, and February (Schultz and others 1955). Active root growth occurs primarily during the drying period starting in late April; by July, roots may extend to 56 inches (142 cm).

The vagaries of weather play an important role in the establishment of seeded species-as evidenced after the 1960 Johnstone fire in southern California. Areas within the burn were chosen as experimental sites for various emergency rehabilitation treatments. High temperatures, winds, and record low rainfall resulted in extremely poor establishment of seeded species the first year; the sites had to be reseeded the following year. The critical first year's data on the establishment of grass (*Lolium rigidum* and *Bromus mollis*) and its influence on reduction of erosion were lost (Corbett and Green 1965).

In summary, specific meteorological conditions are required for ryegrass to successfully establish itself. Mean temperatures should be above 50°F and rains should be gentle and well spaced without periods of intense rainfall. High nutrient availability in the postfire environment enhances ryegrass establishment. Observations and experimental data indicate that much of the precipitation in the first postfire winter can be expected to occur before seeded or native herbaceous species are well established. Studies have shown a wide range in establishment of ryegrass the first year after fire. Ryegrass establishment is quite variable from year to year in response to climatic fluctuations.

Geographic Constraints on Establishment

In 1957, the California Department of Forestry (CDF) began monitoring the establishment of ryegrass in postfire emergency revegetation projects. The results of these studies were published in a series of annual reports on "Emergency Revegetation of Burned Watersheds" (California Division of Forestry 1957-1972). After postfire seeding, permanent plots were set up--usually two plots, of unspecified size, per site--on selected bums and were monitored for 3 years. We identified these projects as occurring either in southern California counties (south of 35°N latitude) or northern California counties (north of 35°N latitude). In these reports, establishment was considered

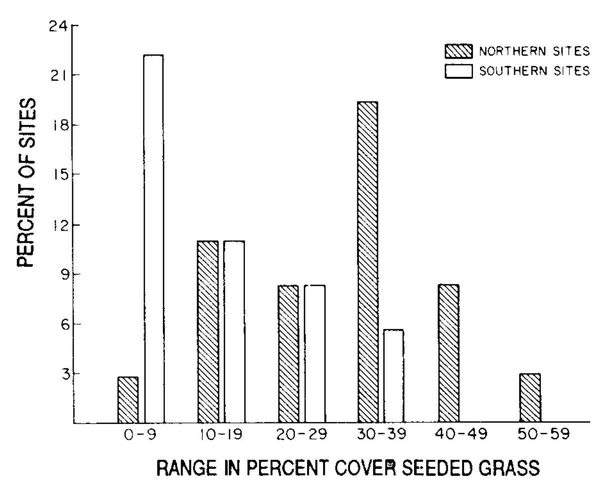

Figure 1-Range of percent ryegrass cover on burned sites the first year after emergency revegetation on northern and southern California sites. Data was compiled from information in CDF emergency revegetation reports (California Division of Forestry 1957-1972) .

successful with first-year ryegrass cover of 30 to 48 percent in northern California and 25 to 28 percent in southern California. We evaluated the data collected by CDF from 36 seeding projects (*fig. 1*).

On the basis of 16 years of CDF annual reports we noticed the following trends:

- The probability of good establishment was much greater in northern than in southern California.
- Most of the unsuccessful reseeding attempts were attributed to poor site quality, high temperatures, low or delayed rainfall, and high winds.
- Even on those projects termed "successful," substantial erosion was noted in some cases.

The CDF annual reports are one of the few sources of information we found on the establishment of grass species (seeded for emergency revegetation purposes) over a comparatively large number and variety of burned areas. As such, the results of these studies are a valuable source of information. Blanford and Gunter (1972) used these same reports to make conclusions on seeding. They divided the seeded areas into three climatic zones (hot summer, cool summer, and cool summer with fog). They found that establishment was best in areas with cool summers and fog and worst in areas with hot summers.

In summary, establishment is strongly influenced by regional climate. Observations and reports indicate that ryegrass establishes better in central and northern California than in southern California and better in cool, moist coastal areas than in hot and dry inland or desert regions.

Ryegrass Persistence

After establishment, the question becomes, How long will the ryegrass remain on the site? Papanastasis (1976) has stated that accumulation of grass mulch, grazing by small rodents, and especially decline in soil fertility contribute to the disappearance of annual ryegrass from a burn site. Dodge (1979) and Biswell (1974) suggest that ryegrass disappears in 3 to 5 years as availability of nutrients in the ash decreases. Corbett and Green (1965), reported that, in areas where high seeding rates of annual grasses were applied, grass cover decreased gradually over 2 years. Few studies have reexamined seeded sites to quantify the changes in amount of seeded grass species present in later years following seeding.

Establishment of Natives and Seeded Species

Several studies have been conducted by land managers to observe responses of vegetation to various management practices. On the Cleveland National Forest, in southern California, burned plots on slopes of 35 to 75 percent slope were seeded with ryegrass at rates of 0 to 40 lbs/acre (Blankenbaker and Ryan 1985). Plots varied in aspect, slope, and percentage of rock but all had the same soil type. Results showed that seeded plots did not have greater vegetative cover than unseeded plots (differences of less than 20 percent could not be detected). Soil erosion was highly variable among plots, so no conclusions could be drawn. In this study, plots seeded with a range of ryegrass densities had minimal ryegrass establishment, and native cover exceeded seeded grass cover in all cases (*table 1*).

After the Panorama fire of 1980, an unreplicated monitoring study was initiated. A variety of seeding treatments, using three grass species at varying densities, were undertaken on the burn site (San Bernardino National Forest 1981). After 6 months the unseeded control site had the highest herbaceous cover (70 percent), followed by sites seeded with zorro fescue (55 percent cover), blando brome (45 percent cover) and ryegrass (15-30 percent cover). Natural revegetation was observed to be greater than expected considering the intensity of the burn. Due to lack of statistical analysis and absence of replication, it is difficult to draw any conclusions from these data. Juhren and others (1955) observed recovery of burned areas in southern California after a 1949 fire. They noted vigorous resprouting of chamise (*Adenostoma fasciculatum*), *Ceanothus*, and *Rhus* as well as dense stands of seeded grass, but no quantitative measurements were made.

After the 1960 Johnstone fire in the San Gabriel Mountains, a variety of emergency rehabilitation measures (both mechanical and vegetative) were tested. These were reported by many researchers (Corbett and Green 1965; Krammes and Hill 1963; Rice and others 1965). Unfortunately, none of the seeded species established themselves the first year due to lack of rainfall, high temperature, and winds. The study plots were reseeded the following year, and the cover of seeded annuals increased over the first year (from 2.2 to 10 percent). Establishment of natives exceeded that of seeded species in all cases. In contrast, Conrad (1979) reported that after the 1968 Glendora Ridge fire--also in the San Gabriel Mountains--seeded ryegrass cover was 40 to 90 percent the first year. Keeley and others (1981) found ryegrass establishment from 10 to 67 percent the first postfire year; establishment of native species was negatively correlated with ryegrass establishment.

In summary, only a few studies have looked concurrently at establishment of ryegrass and native annuals. None have noted the relative timing of establishment. In two monitoring studies, the focus was on establishing grass by using varying densities or species. In both cases, the plant cover on unseeded plots exceeded that on seeded plots. However, public agencies would now be less likely to seed these inland sites than more coastal areas. Establishment is highly dependent on meteorological factors as evidenced by the total failure of seeding efforts after the 1960 Johnstone fire and a 40 to 90 percent ryegrass cover after the 1968 fire (both fires were in the same general geographic area).

Table 1-*Mean vegetative cover of three seeding treatments plus an unseeded control seven months after the fire*

Treatment	Native cover		Ryegrass cover	
	------------*percent*------------			
	Mean	S.E	Mean	S.E.
Unseeded	19.5	5.3	0	0
10 lbs/acre	18.0	9.2	1.0	0.41
20 lbs/acre	22.3	10.7	2.0	1.68
40 lbs/acre	17.3	3.9	0.8	0.48

Source: Blankenbaker and Ryan 1985.

INFLUENCES OF GRASSES ON THE CHAPARRAL SYSTEM

Effectiveness in Reducing Erosion

In a previous section, we outlined how fire in chaparral watersheds causes changes that lead to accelerated erosion rates. This problem has led public agencies and land managers to adopt policies to increase vegetative cover rapidly after fire. Through seeding of fast-growing grass species (especially ryegrass), it is hoped that watersheds will be protected until native species can establish themselves. In other sections, we looked at the meteorological and geographic constraints on ryegrass establishment and some experimental results on ryegrass establishment. This section summarizes the limited data available on effectiveness of ryegrass and native herb species at reducing postfire erosion.

Scope of Past Studies

In past studies examining ryegrass establishment, few measurements of erosion were made, and many times establishment of grass species was equated with erosion reduction. Part of the reason for this is that erosion is highly variable even between adjacent, virtually identical watersheds (Scott and Williams 1978). Blankenbaker and Ryan (1985) found soil erosion was highly variable on the 16 plots in their study of burned chaparral on the Aguanga Ridge in San Diego County.

After ryegrass failed to establish on seeded slopes the first year after the Johnstone fire, the sites were reseeded. Ryegrass was found to be effective in reducing erosion the second year after fire. A 16-percent decrease in production of debris was attributed to ryegrass establishment (Corbett and Green 1965) although flood peaks were unaffected (Krammes and Hill 1963).

The function of native postfire annual species in ecosystem processes has not been studied well. Sweeney (1956) examined how herbaceous species are influenced by specific postfire environmental conditions (soil pH, nutrients, light, etc.) but not how these species influence the environment. Horton and Kraebel (1955) suggested a vague role for postfire annuals in the prevention of rill erosion. Rundel and Parsons (1984) noted that postfire ephemeral herbs played a significant role in the recovery and storage of nutrients (N, P, K, Ca, Mg) on the burn site. No past studies have compared the effectiveness of native annuals and ryegrass (or other seeded grass species) in reducing erosion on newly burned sites.

Long-Term Effects of Type Conversion

Some researchers are concerned that if grass establishes successfully it may not yield later to native species. This would, in effect, be type conversion and could lead to significant changes in sediment production and slope stability. Studies of chaparral areas that have been converted to grass through a combination of seeding and shrub control measures give indications that the shallow root systems of grasses may allow more large-scale slope failures to occur than when slopes are anchored by more deeply rooted shrubs.

Areas on the San Dimas Experimental Forest converted to grass through burning and herbicide application had a significantly different response to precipitation than did brush-covered slopes. Five years after type conversion the area experienced the fourth largest storm in local history. Corbett and Rice (1966) noted that converted areas had had five times the number of soil slips as the nonconverted (control) areas and five times the area in soil slips. The slips occurred at depths corresponding to the interface between the rooting zone of seeded grasses and underlying soil. To further investigate the effectiveness of chaparral in reducing erosion, they compared the frequency of slips on north- and east-facing chaparral-covered slopes (where chaparral grows larger and denser) versus those on south- and west-facing slopes (with sparser chaparral cover). They found five times more slips on south- and west-facing slopes.

Bailey and Rice (1969) also noted the occurrence of soil slips in different vegetation types. They found that the number of soil slips increased along a progression from chaparral (fewest slips) to annual grass to perennial grass and to buckwheat/sage/barren soil (most slips). Thus, stability rendered by various vegetation types was closely related to rooting habit and density of plants.

In summary, it is known that the presence of plant cover on slopes helps to decrease sediment movement. Burned slopes are seeded to rapidly achieve a plant cover and supplement native cover. The effectiveness of ryegrass seeding in decreasing postfire erosion has been the subject of several studies, most of which have been inconclusive due to the high spatial variability in erosion processes. Seeded grasses and native herbs cannot establish themselves soon enough to prevent the dry sediment movement that occurs during and immediately after fire. The effectiveness of ryegrass in reducing the effects of wet erosion will depend on the timing and intensity of rainfall in relation to grass establishment. The role of native annuals in erosion reduction that first critical year after fire, has not been well documented.

Changes in Fuel Characteristics

Some evidence indicates that along with ryegrass establishment on a chaparral site comes the increased potential for an early reburn. Grasses fuels are more prone to fire than chaparral fuels for three basic reasons (Cohen 1986):

- The size-class of fuels shifts toward finer fuels when grasses replace chaparral as the dominant cover. This condition results primarily in rapid rates of fire spread.
- Due to the drying of annual foliage late in the season, a large proportion (100 percent in annual grasses) of the fine fuel is dead. Rapid rates of fire spread can be achieved under a broader range of conditions.
- The fuel beds are more susceptible to an ignition.

Although grass fires are considered by many to be less serious and more easily controlled than chaparral fires, they can have a devastating effect on seedlings of native species. Nadkarni and

Odion (1986) studied a site near Ojai, California, which burned in 1983 and was seeded spottily with annual ryegrass--such that some areas had no ryegrass establishment. A second fire occurred in the same area in July 1985 (Wheeler Fire). Only those study areas where ryegrass had become well established burned in the second fire. Studies are continuing on this site to help elucidate the effects of two burns in close succession on species composition in chaparral.

Zedler and others (1983) reported on a site in San Diego County where near record precipitation resulted in an exceptionally good cover of native herbs and seeded grasses after a 1979 fire. By the following summer (1980), the dead fuel (predominately grass) that had accumulated was enough to carry another fire. The second burn in such close succession had noticeable effects on the native chaparral shrubs. *Ceanothus oliganthus*, an obligate-seeder, was killed by the 1979 fire, but established abundant seedlings postfire (40 times greater than prefire abundance). The second fire destroyed almost all seedlings of *C. oliganthus.* The sprouter-seeder *Adenostoma fasciculatum* suffered high mortality during the first fire but, with seedlings plus surviving resprouts, reestablishment was high. Abundance of *A. fasciculatum* was reduced by 50 to 97 percent after the second fire.

Zedler and others (1983) speculated that openings left by mortality of shrub species after these two fires in close successsion would probably be occupied by soft chaparral species--such as *Artemisia californica* (sagebrush), *Salvia apiana* (white sage), and *Eriogonum fasciculatum* (buckwheat). Since the fuel characteristics of these species are quite different from those of hard chaparral, they predicted that these species might perpetuate themselves for 100 years or more. Thus, seeded ryegrass has the potential to cause long-term changes in chaparral ecosystems.

In summary, because ryegrass has different fuel characteristics from native chaparral vegetation, it provides an easily ignitable fuel bed at an earlier age than would chaparral shrubs. Burning chaparral sites at short intervals can cause significant changes in species density and composition and could potentially allow invasion of soft chaparral species, ultimately leading to conversion to a vegetation complex more fire-prone than hard chaparral.

Changes in Successional Patterns/Competition

During the Pleistocene (past 2 million years), conditions favoring the rapid expansion of chaparral type plants developed. Fossil evidence indicates that long summer drought, limited winter rain, and fire were major factors in chaparral development during this time (Axelrod 1958). Fire continues to play a role in chaparral ecology (Hanes 1971; Keeley and others 1981). Because reproduction of many chaparral species is keyed to fire, many authors consider fire to have been a major selective force in the development of these species. There has been debate over the successional position of chaparral, whether it is an actual climax community or a subclimax due to periodic fires. What is known is that fires do occur periodically in chaparral and that these fires remove dead wood, stimulate basal sprouting and germination of dormant seeds, remove phytotoxic substances in the soil, and increase the concentration of available nitrogen (Christensen and Muller 1975; DeBano and Conrad 1978; Horton and Kraebel 1955; Keeley and Zedler 1978).

Early Postfire Successional Dynamics

Many chaparral shrubs have seeds that require heat scarification before a significant number are able to germinate. In the chaparral--as in other fire-prone environments--plant establishment occurs primarily within the first year after fire for shrub species and within the first 1 to 2 years for herbs. In studies conducted over a period of 17 years in Los Angeles County, Horton and Kraebel (1955) observed only three seedlings of *Ceanothus crassifolius* that emerged after the first postfire year. Sweeney (1956) found that only a few of the thousands of seedlings produced survived the first several years after fire in northern (Lake County) California. After 3 years, seedling populations declined by the following amounts from initial postfire levels: chamise, 98.6 percent; *Ceanothus cuneatus,* 90.7 percent; *C. parryi,* 96.1 percent; *Cercocarpus betuloides,* 72.4 percent.

Even in plots with no herbaceous vegetation, Schultz and others (1955) found that mortality of brush seedlings (*C. cuneatus, C. leucodermis, C. integerrimus,* and *Arctostaphylos mariposa*) was 64 percent in the first year and resulted in 2.8 seedlings/square foot (30 seedlings/square meter). Mortality of typical chaparral shrubs during the first postfire year appears quite variable but frequently exceeds 50 percent, and ranges from 2 to 96 percent (*table 2*). Seedling mortality continues at lower rates for several years (Cronemiller 1959; Horton and Kraebel 1955; Sampson 1944).

Table 2 -*Percent shrub seedling mortality at unseeded sites the first postfire year*

Species	County	Mortality	Source
		percent	
A. fasciculatum	San Diego	39	Keeley & Zedler 1978
A. fasciculatum	Lake	96	Sweeney 1956
Arctostaphylos glandulosa	San Diego	71	Keeley & Zedler 1978
A. glandulosa	San Diego	55	Keeley & Zedler 1978
Arctostaphylos glauca	San Diego	33	Keeley & Zedler 1978
A. glauca	San Diego	44	Keeley & Zedler 1978
Ceanothus cuneatus	Lake	84	Sweeney 1956
C. greggii	San Diego	2	Keeley & Zedler 1978
C. parryi	Lake	88	Sweeney 1956
Cercocarpus betuloides	Lake	62	Sweeney 1956

Source: Adapted from Keeley and Zedler 1978; Sweeney 1956.

The rate of growth and recovery of chaparral stands after fire is dependent on stand composition. A stand of predominately nonsprouting species will not completely reoccupy the site for several years while a stand of sprouting shrubs will generally recover rapidly (Sampson 1944). Biswell (1974) reported that the initiation of sprouting depends on the season of burning. Radosevich and Conard (1980) observed that chamise (*Adenostoma fasciculatum*) regrew from rootcrowns within 6 weeks of the burn regardless of the season of burning. Plumb (1961) noted that sprouting of shrubs and trees began within 10 days of a fire in July in southern California.

Chaparral succession results primarily from changes in dominance and density of species that establish themselves shortly after fire. Obligate-seeding shrubs--which are killed by fire and rely on their seedlings to repopulate a site after fire--may be especially sensitive to disturbances in the immediate postfire environment. Their reestablishment is strongly dependent on environmental conditions at that time. Any factor that inhibits establishment of these obligate-seeding species has the potential to cause major long-term changes in species composition and vegetative structure of chaparral stands.

Influence of Grass on Species Composition

In a study of postfire succession of herbaceous flora at three sites (elevations of 560-1670 m) in San Diego County, California, Keeley and others (1981) found that the total herbaceous cover was about the same in areas of good and poor *Lolium* establishment but that the species composition was different. The success of *Lolium* was apparently at the expense of the native annuals. This is illustrated below by results from two of the study sites.

Site	*Lolium*	Native herbs
	----*percent*-----	
Kitchen Creek	10	47
Alpine	67	3

Nadkarni and Odion (1986) found that species richness (number of species per unit area) also varied with the presence or absence of ryegrass. On seeded plots, species richness was 40 percent lower than on unseeded plots (4.6 spp/m= vs. 7.5 spp/m^2) in Ventura County, California. The shrub *Ceanothus crassifolius* (an obligate-seeder) and the herb *Turricula parryi* were common on unseeded sites, but were absent from seeded sites.

Seeding trials after the 1960 Johnstone fire in the SDEF were reevaluated in 1978. Conrad (1979) found that watersheds that had been seeded with annual grass after the fire had 25 percent less total vegetative cover than unseeded watersheds when reevaluated 18 years later. Soft chaparral species such as *Eriogonum fasciculatum* (buckwheat) and *Salvia mellifera* (black sage) were much more common on seeded watersheds (24 percent cover) than on unneeded watersheds (8-13 percent cover). Similarly, Conrad (1979) observed that where grass cover had been 40 to 90 percent the first year after the Glendora Ridge fire of 1968, vegetative cover 10 years later was heavily weighted toward black sage. Where seeded grass cover had been greater than 60 percent, seedlings of hard chaparral species such as *Adenostoma fasciculatum* and *Ceanothus* species were practically absent.

Table 3-*Root growth of monocultures of ryegrass* (Lolium multiflorum) *and brush* (Ceanothus cuneatus) *seedlings*

Date	Root Depth	
	Ryegrass	Brush seedlings
	--------------cm---- -------------	
January 15	20	0
March 15	30.5	0
March 30	--	15
April 15	58	38
June 30	142	109

Source: Adapted from Schultz and others 1955.

Grass-Shrub Interactions

Schultz and others (1955) conducted studies of chaparral in the foothills of the Sierra Nevada in central California. They found that both the number and vigor of brush seedlings were negatively associated with increasing densities of herbaceous species, especially grass; competition for moisture was thought to be the chief cause. Three months after emergence, wedgeleaf ceanothus (*Ceanothus cuneatus*) growing without competition from other species had roots that penetrated to 43 inches (109 cm) and had 26 inches (66 cm) of lateral growth. In contrast, shrub seedlings growing in a dense stand of ryegrass had a maximum root depth of 11.5 inches (29 cm) with very little branching. The effect of native herbaceous species on growth of shrub seedlings was not examined in this study.

Schultz and others (1955) reported that in central California emergence of brush seedlings (*Ceanothus leucodermis* and *Ceanothus cuneatus*) occurred in mid-March and was 80 percent complete by mid-April. After 3 months (about mid-June), roots of these two species reached depths of 30 to 43 inches (76-109 cm) (*table 3*). The deep roots were the first to develop, with superficial roots coming later.

Grasses emerge earlier than brush seedlings (fall versus spring), and grass basal areas can increase rapidly if environmental conditions are favorable. Schultz and others (1955) noted that it was difficult for the later-emerging shrub seedlings to push their hypocotyls through the mat of grass roots and stems at the soil surface. They found that brush seedling mortality was high the first postfire year.

Even without competition from seeded grasses, Schultz and others (1955) found shrub seedling density was reduced to 2.8 seedlings per square foot. Additional mortality was attributed to the presence of grass if grass cover exceeded 30 percent. In addition, Schultz and coworkers observed that grass roots occupied the upper layers of soil more thoroughly and depleted soil moisture. In a plot with 70 percent ryegrass cover, soil moisture deficiency occurred to a depth of 4 feet while on an unseeded plot, where the only vegetation was brush seedlings, the soil moisture was only depleted to a depth of 6 inches. *Figure 2* illustrates the differential effects of native (resident) annuals and seeded ryegrass on shrub seedlings. Schultz and Biswell (1952) looked at effects of competition of different densities of annual grasses with several perennials. In their study, they found that early growth and extravagant use of water by ryegrass made it a stronger competitor with brush seedlings than were perennial grasses.

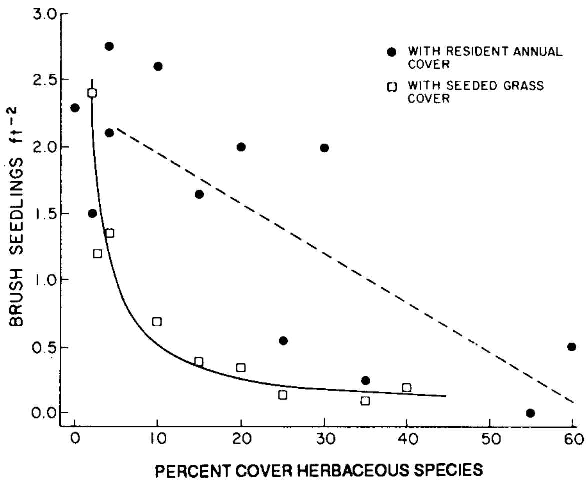

Figure 2--Relationships between density of brush seedlings and canopy cover of ryegrass or resident annuals (adapted from Schultz and others 1955). Modified graph reproduced with permission of the Ecological Society of America from Schultz and others 1955.

In summary, native chaparral species are well adapted to intermittent fire. Obligate-seeding species will normally reestablish themselves on a site only during the first year after fire. At least on some sites ryegrass is a vigorous competitor that can inhibit growth and development of both shrub seedlings and native postfire annuals. The few results that are available also suggest that seeded grasses frequently may not affect total herbaceous cover, but may instead establish themselves at the expense of native annual species and shrub seedlings.

LIMITATIONS OF AVAILABLE INFORMATION

Limitations in Scope

Some of the major limitations of past studies include restricted number of geographic areas used in sampling, short duration (1-2 years) of the studies, and lack of replication in time.

Limited Geographic Areas

Most of the previous studies were done on dry slopes in southern California where soils are, in general, shallow and rocky, rainfall patterns are extremely variable, and slopes are steep. Ryegrass establishment is often not very good under these conditions. In fact, many areas where experiments were conducted would not be seeded based on the current guidelines. Establishment might be expected to be better on gentler slopes with deeper soils and more even rainfall distribution. Studies conducted over a variety of geographic/climatic areas would help clarify the apparently conflicting data from previous studies.

Limited Timeframe

Most of the studies were conducted for only 1 to 2 years after the fire, which does not allow evaluation of long-term changes in vegetative composition or erosion. It is hypothesized that the seeding of grass species on burned areas contributes to a decrease in density of shrubs in later succession. This, in turn, may result in increases in deep-seated erosion, therefore, long-term follow-up comparative studies on seeded and unseeded areas are needed.

Lack of Replication in Time

Successful establishment of ryegrass on a burned site is highly dependent on the timing and intensity of rainfall. However, rainfall patterns, especially in southern California, are quite variable from year to year. Results of an experiment designed to show a relationship between ryegrass establishment and erosion rates in any given year may be strongly influenced by weather patterns that particular year. Studies that are temporally replicated would give a clearer picture of the range of potential responses and would provide a better foundation for management decisions.

Experimental Design Problems

In surveying the literature on ryegrass seeding as an emergency revegetation measure, we have found that many of the past studies had design flaws that made analysis and interpretation of results difficult or impossible. Some of the major problems we identified in the studies we reviewed are outlined below.

Lack of Replication

In some of the studies there is no replication of treatments or sites. This makes generalization and interpretation of results risky or unwarranted. Without adequate replication, field variability cannot be distinguished from differences in treatment responses.

Lack of Control Plots

In some studies, no unseeded control plots were established to be compared against the response of seeded plots. It is, therefore, impossible to determine whether ryegrass is actually increasing total cover or what effects it is having on native species.

Lack of Erosion Measurements

Very few past studies have combined measurements of erosion (using erosion troughs, for example) with a study of the development of cover of ryegrass, native brush seedlings and resprouts, and native herbs. It is difficult to attribute the reduction of erosion to ryegrass cover unless both erosion and the amount of cover of ryegrass as well as that of native species are measured on both seeded and unseeded plots.

FUTURE RESEARCH NEEDS

For nearly 40 years, aerial seeding of ryegrass has been used in emergency rehabilitation of burned watersheds after wildfires. Over this time, there have been extensive opportunities to collect data on the effectiveness of this practice in decreasing erosion. Surprisingly, few good baseline data are available. Reported results are confounded by lack of replication in time or space, lack of controls, and little or no follow-up on shorter term studies. Of the limited results available, many are either unpublished, are published in documents of limited circulation, or are mere side observations of related studies. Due to the above factors, it is necessary to start virtually from the beginning in establishing good baseline data.

More studies need to be done to determine under what conditions the seeding of ryegrass would be most appropriate in ameliorating the effects of accelerated postfire erosion. In deciding whether or not to seed, serious consideration needs to be given to geographic location of burned areas, site characteristics (slope, elevation, aspect, etc.), proximity to population centers and downstream structures, likelihood of major debris flows, potential effects of seeding on native plant recovery, and the ultimate goal of seeding (type conversion or temporary cover).

Although much of the information on ecosystem responses to emergency revegetation is lacking, current emergency revegetation guidelines attempt to take into consideration the following criteria:

- Potential hazards and potential for recovery on each burn site.
- Objectives of the reseeding effort.
- Consideration of natural revegetation as an alternative to ryegrass.
- Need for protection of downstream population centers and values.
- Need for consideration of geographic location as a predictor of success of ryegrass establishment.

So that public agencies can make the wisest possible decisions on emergency treatment of burned watersheds, more solid information resulting from well-designed studies is needed. The following paragraphs outline areas in which we feel future research needs to be focused before many of these questions can be answered:

- We recommend that more studies be conducted in central, northern, and coastal southern California where soils are generally deeper, weather patterns are more favorable, and ryegrass establishment is more often successful. This would help balance the past studies that have focused on interior southern California watersheds where steep, tectonically active slopes, shallow soils, and harsh weather conditions reduce the possibility of successful ryegrass establishment.
- We think that studies should be conducted in areas of varying site characteristics. This would elucidate the effects that slope, soil depth, soil type, elevation, etc., have on the success of ryegrass establishment as well as the effectiveness of ryegrass in preventing erosion on these differing sites.
- We recommend that studies be continued for at least 3 years and ideally 5 to 10 years or more so that we may better understand the successional dynamics of chaparral as well as erosion processes, with and without the presence of ryegrass, through time.
- Studies that pair some measure of erosion with an evaluation of plant cover and density by species (both native and introduced) are necessary to enable possible cause-and-effect relationships to be established between grass cover and erosion, total plant cover and erosion, and grass cover and native cover.
- We think that experiments should be replicated in time to account for temporal variations in weather conditions that might influence the success of establishment of seeded grasses and native species.
- We think that more studies need to test alternatives to the seeding of ryegrass at the current rate. Possible alternatives include seeding at lower rates, using less competitive grass species, or seeding native annuals.
- We think that more studies are needed that evaluate the role of native annuals in slope stabilization and achievement of early cover of burned slopes. Few studies have compared the date of emergence of postfire annuals and grass, and none have compared their relative abilities to reduce erosion.

CONCLUSIONS

Despite a long history of ryegrass seeding to control postfire erosion on chaparral sites, little information exists on the effects of seeding on erosion or on natural succession processes in chaparral. Evidence suggests that the degree of ryegrass establishment is dependent on postfire environmental conditions, but the influences of geographic and annual climatic variability are poorly understood. A relationship between establishment of ryegrass cover and reduction of erosion in the years immediately following fire has not been quantitatively established. Furthermore, seeding ryegrass in the postfire chaparral plant community may affect long-term erosion rates as well as the frequency of reburning. Considerable expense is involved in the reseeding of major fires. It is critical for managers to have accurate information on the effects of grass seeding on erosion processes and succession in chaparral systems.

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The aftereffects of wildland fire in California have become an increasing problem as developments encroach on wildland areas. To alleviate postfire increases in erosion, public agencies often seed burned slopes with grasses (primarily *Lolium multiflorum*) to rapidly increase vegetative cover and protect the slopes from erosive agents such as wind and rain. Questions about the effectiveness of this seeding in reducing erosion have increased in recent years. Many people have observed significant amounts of erosion occurring during and immediately after chaparral fire, before ryegrass has had a chance to establish. The effect of an introduced grass species on long-term species composition and richness is not known. This literature review includes a history of seeding and current seeding practices, and examines the occurrence of accelerated erosion afterfire, addresses meteorological and geographic constraints that influence establishment of seeded ryegrass and native plants, summarizes the information available on the influence of ryegrass on the chaparral system, and gives recommendations for future research.

Retrieval Terms: ryegrass, emergency revegetation, grass seeding, chaparral