Wildfire Preparedness and Recovery in San Diego County
A Review and Analysis White Paper of
Data and Research Studies Relevant to Wildfire

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Table of Contents

Executive Summary

The purpose of this white paper is to provide summaries and analysis of research studies dealing with various aspects of wildfire. The selection of studies to review emphasized those that were *peer-reviewed*, which means the study was reviewed and analyzed for validity and accuracy by anonymous experts familiar with the subject area. Studies reviewed in this white paper that *are not* peer-reviewed are designated with an asterisk in the reference section. A total of 106 studies or sources of data are cited in this paper. Of this total, 79 studies were peer-reviewed. The remaining 27 sources were studies or web site data not peer-reviewed.

Topic addressed in this paper include:

- Fire History in San Diego County
- Fire Regimes
- Fire Effects in Chaparral and Coastal Sage Scrub
- Fire Effects in Desert Ecosystems
- Fire Effects in Forest Ecosystems
- Fire Effects on Wildlife
- Fire Effects on Soil and Water Quality
- Fire and Structures
- Defensible Space
- Post-fire Restoration

Fire History in San Diego

There have been thousands of wildfires ranging from insignificant to catastrophic in San Diego County throughout the last century to the present. These wildfires have had both natural and human causes. Government and university sources of fire statistics, data, and maps are available specifically for San Diego County. California Department of Forestry and Fire (CDF) lists a total of 522 fires burning over 300 acres in San Diego County from 1910 to 2004. The most devastating fires by far occurred in October 2003. Even with the availability of modern fire suppression, statistics from the last few decades still show the regular occurrence of larger fires burning over 300 acres. Although research studies were not found specifically addressing the fire history in San Diego County, many do address the patterns of fire that have occurred in southern California in the following section on “Fire Regimes.”

Fire Regimes

There are 14 studies discussed in this section. Nine of the 14 articles address an ongoing debate regarding how a "natural" fire regime in southern California would function in the absence of human intervention, and how this should affect current vegetation fuel management. In summary, one side argues that fire suppression has altered the natural fire regime. Large fires are now more frequent, and management should focus on using small, frequent fires across the landscape that re-create patches of different ages of vegetation. The other side argues that large fires have always been and will always be a part of the southern California fire regime. Weather is the dominant control of large fires, and management should focus on strategic areas in the urban-wildland interface. One item agreed upon by both sides is that future development into wildlands is only doomed for future encounters with wildfire that may be very difficult to control.

Fire Effects in Chaparral and Coastal Sage Scrub

A total of twenty studies are addressed in this section. Wildfire is a major influence in both chaparral and coastal sage scrub with some species requiring fire as part of their lifecycle. Many research studies have been done on these types of vegetation, although more study appears to have been done on post-fire regeneration of chaparral than coastal sage scrub. All studies except one appeared in peer-reviewed journals and did not seem to produce contradicting information. The one study that was not peer-reviewed was the County of San Diego's Department of Planning and Land Use October 2003 post-fire report. Due to the number and interaction of factors that can affect post-fire chaparral recovery, the results observed after different fires at different locations may vary both in plant composition and rate of return. One serious problem that can occur in both chaparral and coastal sage scrub is the introduction and establishment of invasive grasses when fire intervals are too short. Two studies showed that herbivores, such as deer and small mammals, can impact the post-fire recovery of native chaparral species.

Fire Effects in Desert Ecosystems

Eight studies are discussed in this section, six of which were produced by the same researcher. All eight studies were limited to the Sonoran and Mojave Deserts and show the differences between fire in the desert and other ecosystems such as chaparral/coastal sage and forests. Fire is less frequent in the desert and many perennials, such as creosote bush scrub are poorly adapted to fire. However, fire is still a natural event in the desert and fire suppression allows fuels to build up. These studies all emphasized the negative impacts of exotic grasses.

Fire Effects in Forest Ecosystems

Compared to chaparral/coastal sage and desert ecosystems, there is limited data for forest ecosystems in San Diego with only four studies cited in this section. A similar argument regarding fire regimes in chaparral is repeated for forest ecosystems. The first study is an October 2003 post-fire report by the County of San Diego Department of Planning and Land Use that is not peer-reviewed. The second report again contends that fire suppression in southern California forests has the negative effect of allowing vegetative fuels to build up and creates larger fires. The third study argues that weather is the driving force behind fire intensity in boreal and subalpine forests. The fourth source is a report from San Diego Biological Resource Researchers, which is a synthesis document based upon informed opinion. The report is a compilation of summaries based on post-fire observations of various floral and faunal communities after the 2003 fires.

Fire Effects on Wildlife

A total of nine studies are discussed on fire effects on wildlife. Two studies involve desert ecosystems, five studies involve chaparral/coastal sage scrub/grassland ecosystems, and two studies involve forest ecosystems. The desert studies show that fire can directly kill vertebrates and the Desert Tortoise is negatively impacted by loss of habitat. The studies in chaparral and coastal sage showed that loss of habitat, which provides food and cover, is a problem for wildlife in post-fire landscapes. The two forest studies did not deal specifically with wildfire. The first study dealt with the impacts of prescribed fires for fuel reduction and the second study used a slash burn to determine if fire could be used to control seed-eating mice that hinder reforestation.

Fire Effects on Soil and Water Quality

Nine studies are discussed in this section. Three of the studies deal with chaparral ecosystems. Erosion is acknowledged to be a problem in post-fire chaparral with one researcher suggesting that severe flooding and erosion do not end until after three years and stormflows do not return to normal for five to ten years. Another researcher discussing forest and rangeland claims that wildfires can create water-repellant layers in chaparral, which result in more runoff. Light prescribed burns should have minimal hydrologic impact on watersheds, but wildfires may have a significant effect. The most recent article in this section suggests that belowground impacts of a fire are a result of the severity of the fire. Three articles are cited from the late sixties that were presented at the University of California Riverside Symposium on Water-Repellant soils, which was not peer-reviewed.

Fire and Structures

A total of seventeen studies discuss fire and structures. Topics addressed include: interior and exterior wall linings, insulation, fire-retardant treatments, mortar, deck board materials, roofing, overall design, and fire detectors. Much of this section focuses on construction standards, testing, and test protocols, and involves technical data that is likely of most interest to the construction and building materials industry. Testing is done on building materials to evaluate their reaction to fire. In some cases, even the test protocols themselves are tested. The test protocols used for much of the research referred to in this section come from ASTM International, originally known as American Society for Testing and Materials. Many of the research articles appearing in a scientific journal from this section were found in *Fire and Materials,* an international journal directed at the fire properties of materials and the products into which they are made. Much of the research is international, with many studies coming from Canada.

Defensible Space

A total of ten studies discuss defensible space. Five of the studies are by the same USDA Forest Service researcher. All five studies essentially repeat the same theme that vegetation management is necessary in approximately the 40 meters (44 yards) around a structure to prevent direct ignition from flames. Using noncombustible exterior materials is necessary to prevent ignition from firebrands (burning embers) that may come from further distances. This researcher contends that the homeowner has a primary responsibility in protecting their residence. A second USDA researcher repeats the idea of homeowner responsibility and adds that the public and policy makers need to be informed to avoid making bad land use and zoning decisions that hinder fire protection. A literature review from the Center for Biological Diversity, which is not peer-reviewed, suggests 60 meters (66 yards) versus 40 meters (44 yards) to provide a safety margin to account for steep slopes or tall trees that could produce scorching of exterior walls. An Australian study on three large historical fires found that the maximum distance at which homes were destroyed was typically found to be less than 700 meters (675 yards). However, this study did not address the building and roof materials of these homes, nor the vegetation located directly around the structures.

Post-fire Restoration Practices

Eight studies are discussed in this section on Post-Fire Restoration Practices. Each deals with a slightly different aspect or issue of post-fire restoration. The first study attempts to define what good ecological restoration should involve and suggests that historical, social, cultural, political, aesthetic, and moral aspects should be considered as well as technical aspects.
Two articles dealt with post-fire erosion control measures, the first analyzing the erosion control effectiveness of different treatments and the second evaluating the effect of erosion control on native vegetation regeneration. Two studies on coastal sage restoration show the problems presented by competition from exotic grasses. A study on wildlife habitat restoration suggests that the factors of space and time must be considered and makes practical suggestions for doing a wildlife habitat restoration project. The final study addresses the impact that post-fire soils in chaparral may have on plant rehabilitation, particularly the impact of lost nutrients. This study refers mostly to Arizona chaparral, but comparisons and references are made to California chaparral.

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Wildfire can be defined as an unplanned and uncontrolled fire event that can have both human and natural causes. Wildfires resulting from natural causes have always been a natural part of much of San Diego County's environment from the desert to the coast. In the past century, attempts have been made to control wildfires for protection and to manage the land. However, wildfires have remained and will always be a regular part of San Diego County's landscape. The October 2003 wildfires displayed the overwhelming power and catastrophic damage that can happen with very large fires. Wildfire preparedness and recovery are essential to minimize loss of life and property while managing and preserving natural resources. This is particularly important as San Diego County's population increases and development continues to spread into wild lands.

The purpose of this white paper is to provide summaries and analysis of research studies dealing with various aspects of wildfire. The selection of studies to review emphasized those that were *peer-reviewed*, which means the study was reviewed and analyzed for validity and accuracy by anonymous experts familiar with the subject area. Studies reviewed in this white paper that *are not* peer-reviewed are designated with an asterisk in the reference section. A total of 106 studies or sources of data are cited in this paper. Of this total, 79 studies were peer-reviewed. The remaining 27 sources were studies or web site data not peer-reviewed.

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Fire History in San Diego County

There have been thousands of wildfires ranging from insignificant to catastrophic in San Diego County throughout the last century to the present. These wildfires have had both natural and human causes. Government and university sources of fire statistics, data, and maps are available specifically for San Diego County.

Discussion of Data – Fire History in San Diego County

The California Department of Forestry and Fire (CDF) provides historical statistics on fires *greater than 300 acres in San Diego County*. This data, entitled "Large and Damaging Fires – San Diego Unit," dates from 1910 to the present and lists the name of each fire, location, date and time, acreage burned, and cause. A total of 522 fires are listed from 1910 to 2004 that burned over 300 acres in San Diego County. In this 94-year period, only five years did not experience a fire that burned at least 300 acres. The years 1911 and 1995 had the greatest number of these larger fires, with eighteen in each year. The most devastating fires by far occurred in October 2003. Even with the availability of modern fire suppression, statistics from the last few decades show the regular occurrence of large fires burning over 300 acres. Listed causes of fires include: lightening, arson, smoking, campfires, fireworks, military activities, equipment use, railroads, burning debris, power lines, bee smokers, and hunting/shooting ("California Department of Forestry and Fire Protection," 2005).

The CDF website also provides historical statistics for all of California. This information includes: twenty largest fires by acres burned and by structures destroyed; fires/acres/dollar damage from 1943 – 2004; individual fire season summaries and large fire lists from 1999-2004; suppression costs; fires caused by arson; fires caused by lightening; and timberland acres burned ("Historical Statistics," n.d.).

The San Diego Fire-Rescue Department website provides brief narrative summaries of eleven "major" fire incidents that occurred in urban and residential areas over the last century. These fires involved such things as a shipping freighter, railroad oil tanker, furniture store, an airliner crash, and old buildings in Balboa Park ("Major Fire Incidents," n.d.).

GIS maps from various sources are available containing fire information for San Diego County. These maps include:

- Fires by Decade for San Diego – San Diego County (SanGIS)

- San Diego County Hazard Severity Zones – Fire and Resource Program of CDF (FRAP)
- Southern California October 2003 Fires – FRAP
- State of California Fire Perimeters – FRAP
- Fire History and Fire Frequency in San Diego County – SDSU Department of Geography
- Fires in Southern California 2003 – NASA

National fire statistics can be found at federal government agency websites. The U.S. Fire Administration (USFA) maintains the National Fire Incident Reporting System online that provides fire loss information for each state (United State Fire Administration, n.d.). The National Interagency Fire Center (NIFC) provides national statistics on wildland fires that includes federal government suppression costs from 1960 to the present (National Interagency Fire Center, n.d.).

Analysis of Data – Fire History in San Diego County

The statistical information from CDF is likely the most comprehensive and accurate information available on fire history in San Diego County, although at that time of this writing, the most updated and accurate statistics on the October 2003 wildfires were found at the County of San Diego website (County of San Diego Department of Public Works, 2004). Although research studies were not found specifically addressing the fire history in San Diego County, many do address the patterns of fire that have occurred in southern California in the following section on "Fire Regimes."

Fire Regimes

Wildland fires occur over time with variations in frequency, intensity, and amount of fuel consumed. The term "fire regime" refers to these patterns. Humans can affect fire regimes by igniting and suppressing fires. Fire suppression is all work and activities connected with fire-extinguishing operations, beginning with discovery and continuing until the fire is completely extinguished.

Discussion of Data – Fire Regimes

A debate exists over whether modern fire suppression has ultimately resulted in larger fires. One researcher contends that suppressing fires allows vegetative material to build up, which provides the fuel for very large fires. Occasional smaller fires would remove vegetation in patches across the landscape to create a "mosaic" of different vegetation ages that will prevent large fires from burning readily across the landscape. A study was done that reconstructed the fire history between 1972 and 1980 of Baja California (Mexico) and southern California (U.S.A.) using Landsat imagery, which produced a model of different fire regimes in Baja and southern California. This study concluded that fire suppression in southern California has led to larger fires, particularly in chaparral that becomes an unbroken carpet of mature vegetation. In Baja, which lacks effective fire suppression and has a heavy population which causes frequent fires, the chaparral is a diverse, "fine-grained patch mosaic" (Minnich, 1983). Another study on Mt. Wilson in the San Gabriel Mountains at the turn of the century also concludes that many small fires were a regular feature on the landscape. The large fires that occurred early in the 20th century happened after a couple decades of fire suppression (Minnich, 1987).

Other studies show that large fires have always existed, even before fire suppression. One study cites data from nine California counties dating back through the 20th century that shows no increase in mean fire size (Keeley, 1999). Another researcher also concludes that large fires have always been a part of the chaparral fire regime from a study of the soil charcoal record that reconstructs the 560 years between 1425 and 1985 in the Santa Barbara Basin. Although fire suppression may contribute to large fires by allowing more vegetative fuel buildup, fire suppression alone does not create large fires. Large fires seem to correlate more with weather conditions, consistently occurring at the end of wet periods and the beginning of droughts (Mensing, 1999). A response to the study in Baja and southern California argues that apparent fire regime differences can be explained by climate differences and the fact that fires are more frequent in Baja due to human ignitions (Keeley, 2001).

Based on ideas about how a natural fire regime in southern California would function, management recommendations are made on how to best manage the vegetation that builds up and provides fuels for wildfire. One idea is to utilize widespread landscape management that uses regular moderate-sized burns to create vegetation patches of different ages, or a "patch mosaic." This type of management would most closely resemble the natural fire regime in place before modern fire suppression, which is argued to have naturally produced frequent small fires (Minnich, 2001). However, another researcher argues that a computer model analysis of fire history data from the Los Padres National Forest shows that fire interval distributions were highly variable, displaying little preference for burning or avoiding plants in particular age classes. Other sources are cited that claim that weather and climate are the dominant controls of chaparral fire regimes as opposed to age and spatial pattern of vegetative fuels. Fires during extreme weather conditions have been capable of burning through all age classes of vegetation (Moritz, 2003).

Another management strategy focuses on strategic locations along the urban-wildland interface, where intensive fuel management can be used to create buffer zones. This is argued to be a more feasible alternative to widespread landscape management that is unlikely to ever be a viable strategy. Widespread management is argued to be ineffective against the most dangerous fires and not economically feasible or possible within the timeframe of burning opportunity allowed for air quality restrictions (Keeley, 2002).

Fire regimes impact the vegetation types found on the landscape. A computer model called Landscape Disturbance and Succession (LANDIS) examined the effect different fire frequencies would have over a period of 500 years in the shrublands and forests of southern California. Infrequent fire regimes (every 1,050 years) were dominated by shade tolerant and long-lived plant types. Shorter-lived and less shade tolerant seeders and resprouters disappeared from the landscape. In the moderate fire regime (every 70 years), similar to what is considered the current fire regime in southern California, the facultative resprouter survived, but the obligate seeder disappeared. The frequent fire regime (every 35 years) was similar to the moderate regime, but all plant types survived with a more even cover (Franklin, 2001).

A literature review discussed the impacts invasive exotic plants can have on native ecosystems by changing the fire regime. If fire regime factors, such as fire frequency or intensity, are changed to encourage the dominance of invasive plants, an "invasive plant – fire regime cycle" can be established. This can be very difficult to reverse. In Western North America, cheatgrass *(Bromus tectorum)* has increased fire frequency to the point that some native species cannot recover. Giant reed *(Arundo donax)* increases vertical continuity in fires and changes surface fires into crown fires. A model is presented that describes the relationships between invasive plants and fire regimes and offers a system to evaluate situations and do restoration (Brooks, 2004).

Another literature review also discussed how invasive plants are impacting fire regimes on an even larger scale. Biological invasions by exotic grasses are argued to be widespread and to have regional and global significance. In North America, grass invasions are more severe in the arid and semi-arid west. Grass invasions are important because their invasions are common, they compete effectively with native species, they can alter ecosystem processes, and many grass species tolerate or even enhance fire. An argument is made that regional and global changes are significant to the point that much of the earth's surface is being driven towards dominance by fire and grasses (D'Antonio, 1992).

Two studies examined the effect the El Niño-Southern Oscillation (ENSO) weather phenomenon has on fire regimes. It is generally observed that fire in the southern United States tends to decrease during El Niño years (which are wet) and increase during La Niña years (which are dry). The first study examined fire history and climate change in five separate giant sequoia groves of the Sierra Nevada by reconstructing their fire history of the past 2000 years. Long-term fire frequencies were similar among the widely dispersed groves, suggesting that climate is the likely cause. Fire occurrence was inversely related to precipitation – more frequent in dry years, less frequent in wet years. Fire frequencies also appeared to be clearly non-stationary and changing through time. This researcher believes this supports the view that ecosystems change through time, rather than tend toward climax and stability (Swetnam, 1993).

A second study also examined the effect of the ENSO weather phenomenon by comparing the forest fire histories of the southwestern United States and northern Patagonia, Argentina, two ENSO-sensitive regions with similar fire-climate relationships. Major fires tend to follow the switching from El Niño to La Niña conditions. Fire occurrences on a decade scale since the mid-17th century are highly similar in both places. This is tentatively interpreted to mean that the synchronization between the two locations is a response to changes in ENSO activity (Kitzberger, 2001).

After the October 2003 wildfires in southern California, which burned 742,000 acres and destroyed 3,361 homes and 26 lives, three researchers made some observations and concluded three lessons to be learned from these fires: 1) although the fires were massive, their size was not unprecedented and similar fires can be expected in the future, 2) the current fire management policy is not effective at preventing these massive fires, and 3) future development needs to plan for these natural fire events. The factors leading up to the fires were very different between forests and shrublands; forests comprised about five percent of the burned area. It was also noted that both the Cedar and Otay fires burned through young vegetation, supporting the argument that different age classes of vegetation will not stop the largest of fires under certain weather conditions. These researchers recommended that fuel management should focus on the wildland-urban interface. Through a combination of buffer zones and better planning, an environment may be formed that minimizes the impact of fire on property and lives (Keeley, 2004). (Note: See analysis below for comment on accuracy of article statistics.)

Analysis of Data – Fire Regimes

A total of fourteen studies are discussed in this section on fire regimes. Nine of the fourteen articles address an ongoing debate regarding how a "natural" fire regime in southern California would function in the absence of human intervention, and how this should affect current vegetation fuel management. In summary, one side argues that fire suppression has altered the natural fire regime. Large fires are now more frequent, and management should focus on using small, frequent fires across the landscape that re-create patches of different ages of vegetation. The other side argues that large fires have always been and will always be a part of the southern California fire regime, weather is the dominant control of large fires, and management should focus on strategic areas in the urban-wildland interface. The idea that weather and climate are dominant controls in fire regimes is repeated in the two articles that argue El Niño/La Niña conditions correspond with higher fire frequencies in forest ecosystems. However, these two studies were not directly part of the debate. Both sides of this long ongoing debate, essentially between two researchers, produced legitimate studies supported and cited by other researchers. After over twenty years of debate, it seems unlikely that the question of what a natural fire regime in southern California should involve and what has been the result of modern fire suppression will be agreed upon and firmly resolved in the near future. The opposing suggestions for vegetation fuel management will likely have to be examined for feasibility and likelihood of success in the current situation. One item agreed upon by both sides is that future development into wildlands is only doomed for future encounters with wildfire that may be very difficult to control.

Two other articles in this section focused on the impacts fire regimes have on vegetation, and conversely, how vegetation can impact the fire regime. The study that examined the effect of different fire frequencies on vegetation used a computer model that was acknowledged by the researcher to be potentially limited in its ability to do simulations and predictions. It might be interesting to note that this model predicts that the plant group "obligate seeders," which relies on fire to reproduce, will eventually disappear under a moderate fire regime that is considered to currently be in place. The study on the impacts of invasive plants on fire regimes highlights the management difficulty that arises when exotic grasses replace native plants. The lead researcher of this study has written extensively on invasive plant issues and is responsible for eight studies cited in this paper. The model presented in this study to evaluate invasive plant situations and conduct restoration may be a useful management tool.

The article written after the October 2003 wildfires contains damage statistics that are mostly accurate but slightly low. This is likely due to the fact that complete damage assessment takes place over time after fires. California Department of Forestry and Fire cites just over 750,000 acres, compared to 742,000 quoted in the article, for all fourteen fires that burned in southern California in October 2003. However, CDF also acknowledges that fire statistics were still being tabulated at the time they compiled their statistics (California Department of Forestry and Fire Protection, n.d.).

Fire Effects on Chaparral and Coastal Sage Scrub

Chaparral and coastal sage scrub are two native vegetation types common to San Diego's natural landscape. Chaparral is an evergreen shrub while coastal sage scrub is comprised of deciduous or semideciduous shrubs. Coastal sage scrub is sometimes called "soft-chaparral". Chaparral is more dominant with coastal sage scrub restricted to drier sites at lower elevations or on shallow soils at higher elevations. Coastal sage is smaller in stature and more open, which allows more herbs to grow around it than the more densely growing chaparral. Coastal sage is often replaced by annual grassland when disturbances are too frequent.

Common species of chaparral include: manzanita, chamise, cup-leaf lilac, and chaparral whitethorn. Chaparral can be found as a stand of one particular species or in mixed stands. Common species of coastal sage scrub include: coastal sagebrush, California encelia, California buckwheat, and black, purple, or white sage.

Wildfire is a major influence in both chaparral and coastal sage scrub. Some species even require fire as part of their lifecycle. Different plant species have different responses and levels of sensitivity to fire:

- obligate seeder (fire sensitive) - depends on fire to cue germination from seed banks in the soil. These plants cannot resprout on their own.
- obligate resprouter (fire resistant) – re-establishes after fire primarily through vigorous sprouting
- facultative seeder-sprouter (fire tolerant) – regenerate either from sprouting or seedling establishment after fire

After a disturbance such as fire, previously growing plant species will begin to re-establish themselves. Some new plant species may be present. The rate at which species establish themselves and dominate on the landscape may vary over growing seasons. In an ecosystem, the term "succession" is used to describe the pattern or sequence in which one plant community replaces another over time. Succession may eventually end in a climax community, or a plant community that is relatively stable and does not change.

After a fire, plants that function best in the conditions of a post-fire landscape will thrive first. Other plant communities may return more slowly but may eventually out-compete some of the first groups of plants for resources. Eventually, the landscape may return to its former climax community. In other cases, exotic plant species may out-compete native plants for resources and the plant community on the landscape will change. This is called a type-conversion change.

Discussion of Data – Fire Effects on Chaparral and Coastal Sage Scrub

The County of San Diego Department of Planning and Land Use (DPLU) reported the acreages burned of different vegetation communities for the October 2003 wildfires using the MODIS (Moderate Resolution Imaging Spectroradiometer) fire boundary. Chaparral comprised the majority of vegetation type burned with a total of 131,370 acres. Coastal sage scrub lost the second highest amount of area with 43,842 acres burned (County of San Diego Department of Planning and Land Use, 2004).

A chapter in a book entitled "Chaparral, and Survival in Southern California" provides general descriptions of chaparral types including: red shanks, ceanothus, chamise, mixed chaparral, manzanita, scrub oak, and montane. Obligate resprouter chaparral species include Toyon *(Heteromeles arbutifolia)* and holly-leafed cherry *(Prunus ilicifolia).* Obligate seeder chaparral species include Cupleaf ceanothus *(Ceanothus greggii)* and bigberry manzanita *(Arctostaphylos glauca)*. Facultative seeder chaparral species include chamise *(Adenostoma* *fasciculatum)* and laurel sumac *(Malosma laurina).* Under natural fire regimes, chaparral replaces chaparral. But as fire frequencies increase, exotic grass and weeds can easily establish themselves and begin the process of type conversion (Halsey, 2005).

Chaparral in southern California is composed of several hundred species. The pattern and rate of change after fire, or succession, are not well known for the chaparral of southern California. Chaparral succession, both in the species composition and rate of change, is believed to be influenced most by aspect, or slope direction. The next important factor is the influence of exposure to the coast and the desert. Fewer chaparral species occur in the desert and succession after fire is slow there. The elevation at a particular site may compensate for the aspect or coastal/desert exposure, due to elevation's impact on precipitation. Coastal chaparral succession is fastest on north slopes above 3,000 feet elevation and slowest on south slopes below 3,000 feet elevation (Hanes, 1971).

Aspect describes the direction a slope faces on the landscape. This affects how much sun, or solar radiation, a slope receives, which in turn impacts soil heating and levels of soil moisture. North-facing slopes receive less sun than south-facing slopes. Therefore, north-facing slopes tend to have higher moisture levels, while south-facing slopes dry out faster. North-facing slopes are deeper and nutritionally richer than south-facing slopes. After fire in chaparral, north-facing slopes have higher plant diversity, a higher species turnover rate over time, and faster vegetation recovery. One probable reason for this is the presence of more nitrogen-fixing plants on north slopes. Nitrogen-fixing plants have the ability to "fix" nitrogen from the atmosphere into a usable form of nitrogen for plants (Gou, 2001). Slope direction may have more impact at lower elevations. Chaparral shrub cover four years after fire is similar between slope faces at higher elevations. At lower elevations (1,800 feet), north- and east-facing slopes have twice the chaparral cover as south- and west-facing slopes four years after fire (Keeley, 1981). Along with aspect preferences, some herbs and vines in post-fire chaparral and coastal sage scrub prefer certain soil types (O'Leary, 1988).

Different plant species thrive at different elevations due to differing levels of precipitation and temperature, which can also affect post-fire succession. Chaparral recovery is faster at higher elevations, likely due to increased precipitation. Four years after fire, shrub cover has shown to be 55% at 5,500 feet elevation but only 28% at 1,800 feet elevation (Keeley, 1981).

Manzanita *(Arctostaphylos glandulosa)* is one common chaparral species found at higher elevations where winter snow and frost are common. It is often termed "cold chaparral." Manzanita can reproduce both by resprouting and seedling establishment. After fire, it produces a large number of seedlings, as does the chaparral species chamise *(Adenostoma fasciculatum)*. But the seedlings of both species are suspected of seldom contributing to mature chaparral cover. Post-fire chaparral succession at higher elevations is similar to lower elevation chaparral, but appears to be more rapid. The location of ash layers and resulting pH change are believed to be one of the most important factors in determining shrub distribution patterns after fire. Manzanita and *Ceonothus* seedlings are most numerous on gentle slopes or level sites where deep ash layers accumulate. However, chamise seedlings grow on steeper slopes, where little ash is deposited. Fires are believed to occur less frequently in upper elevation chaparral, maybe once or twice a century. More frequent fires would likely be detrimental to manzanita and favor other species. This would have implications if controlled burns were to be used in reducing fuel loads. Burning should be done less frequently in upper elevation chaparral than in lower elevation chamise chaparral or higher elevation coniferous forests (Vogl, 1972).

Burning alters most nutrient cycles in chaparral. Nutrient minerals are lost through the burning of shrubs, litter, and humus, but large quantities of minerals are also added to the soil as ash. Burned areas also have higher pH, which enhances the chemical processes that contribute nutrients to the soil. These enriched soil-nutrient conditions enhance the growth of herbs and shrubs in chamise chaparral after fire (Christensen, 1975).

Some plants produce toxic or allelopathic chemicals that inhibit the growth of other plants around them. Both chamise and manzanita chaparral have been shown to produce chemicals that suppress the seedling growth and germination for a number of herb species. After fire, the removal of chamise and manzanita contributes to an initial growth of herb and shrub species that would normally be inhibited by their allelopathic chemicals. These toxic chemicals do not kill the dormant seeds in the soil of certain herb and shrub species, but germination of their seedlings is inhibited. As chamise and manzanita begin to re-establish themselves, their toxic chemicals once again inhibit sensitive plant species. The seeds of these herb species will remain dormant in the soil until the next fire (Christensen, 1975).

Fires remove mature plant cover and expose the previously shaded soil to sun, which increases the soil temperature. Soil heating has been found to enhance the germination of several species of herbs and shrubs. It appears that the dormancy of some seeds in the soil can be broken by this increased soil heating (Christensen, 1975).

The heat from fire can also affect seeds in the soil. Fire varies in intensity and the amount of heat it produces. This can be impacted by the amount of brush that burned. This variation in heat can affect the germination of shrubs and herbs in chaparral. A normal fire can enhance the germination of chamise *(Adenostoma fasciculatum)*, but increasing fire intensity will decrease germination. Cupleaf-lilac *(Ceanothus greggii)* will increase germination with increasing fire intensity, but the very hottest fires will decrease germination. Chamise can reproduce by either resprouting or seeds (facultative-seeder) but cupleaf-lilac reproduces only by seeds that require fire to cue their germination. Obligate seeders may be more resistant to fire than facultative seeders (Moreno, 1991).

California poppy *(Eschscholzia californica)* also shows sensitivity to high heat from fire and germination may be reduced. But the smoke greatly improves seed germination for wild populations of California poppy. The seeds of domesticated California poppy plants do not have dormancy. Because California poppy and other native plants are sometimes used in re-vegetation and restoration projects, it is necessary to understand seed germination. The smoke treatments from prescribed fires may be useful for seed germination in poppy management as long as the heat does not reach the poppy seeds in the soil. The use of synthetic "liquid smoke" may be an alternative to prescribed fire. Non-dormant domesticated seeds are not appropriate for post-fire restoration, particularly in environments that naturally support plants with dormant seeds (Montalvo, 2002).

As already discussed, plants can reproduce in different ways and respond differently to fire. Both resprouting and seeding chaparral species from the genera *Arctostaphylos* and *Ceanothus* show good recovery from fire. After fire, the plants of seeding species suffer complete mortality, but mortality varies in the sprouting species. The greater mortality in seeding species seems to be balanced out by their higher probability of seedling establishment. Overall, chaparral appears to be adapted to both short and long fire-free periods, which would reflect the unpredictability of fire. In a very short fire interval, the obligate seeders will be at a disadvantage because they do not have time to reproduce seed and the existing seedlings are eliminated in the fire with no new seed to germinate. Obligate seeders do well in long fire-free periods because the vegetative fuel has built up and produces an intense fire that clears more openings for seedlings to establish themselves. They can compete better with sprouting species in this situation. It is suggested that occasional long fire-free periods have encouraged the natural evolutionary existence of obligate seeding species (Keeley, 1978).

Some chaparral species can reproduce both by resprouting and by seed, and the proportion of resprouts to seeds will vary with each species. Elevation may also affect which mode is more predominant within a species. Chamise reproduced more by resprouting at high elevation than low elevation. But Nuttall's scrub oak *(Quercus dumosa)* reproduced 100% by resprouting at low elevation and much less at high elevation. Chaparral species that reproduce only by seed will do so in the first year after fire, with the exception of cupleaf-lilac *(Ceanothus greggii)* that does not reproduce until the second post-fire year at high elevation, or 5,600 feet (Keeley, 1981).

Geophytes are a perennial plant group found in California chaparral that propagate by over-wintering buds that are below the soil surface. Their buds are buried deeply enough to survive fire. They flower profusely the first spring after a fire, but may flower only sporadically in following years and remain growing under the chaparral canopy. This is in contrast to most herbaceous plants that initially thrive in the post-fire landscape but do not remain when the chaparral canopy returns. It is not clear exactly how geophytes persist between fires when they only produce seed immediately after fire. It is also not known whether fire is required for them to reproduce. One particular geophyte species, Star Lily or Chaparral Zygadene *(Zigadenus fremontii)*, is very conspicuous in post-fire chaparral. It flowers the first year after fire and produces seedlings the third year. There appears to be a cost of reproduction after flowering. Plants that flowered had lower growth rates in subsequent years than those that did not. These plants do not go dormant, contrary to what has been suggested for geophyte persistence between fires. It is suggested that reproduction after fire depends on growth and carbohydrate storage that occurs between fires. It is also suggested this particular species is relatively long-lived for an herbaceous perennial (Tyler, 2002).

The herbs that first grow after fire in chaparral form a temporary plant cover that declines over the years as the chaparral shrubs return. The level of temporary plant cover that grows in the first year after fire is unrelated to the level of chaparral shrubs that also regenerate that year, but rather is closely tied to the amount of precipitation (Keeley, 1981). The growth of herbs is also made possible by the lack of small mammals that are virtually nonexistent after fire because the bare landscape lacks the cover and protection of mature chaparral plants. This lack of herbivores and the reduction in grazing is shown to contribute to the survival of herb seedlings that first begin to grow after fire in chamise chaparral. In mature chaparral, it is believed that animals eat a large portion of herb seedlings that grow under the canopy. This grazing, among other factors, has a considerable impact on herb seedling survival in mature chaparral (Christensen, 1975).

A very short time between fires, or short fire interval, can cause drastic changes in chaparral. After two fires in 1979 and 1980 on Otay Mountain, *Ceanothus oliganthus* was almost completely eliminated and chamise *(Adenostoma fasciculatum)* was reduced by 97%. The introduction of aggressive annual grasses was believed to contribute to these instances of abrupt change (Zedler, 1983).

A 1966 study noted that chaparral fire in the Sierra Nevada foothills did not eliminate any species, but there are definite changes in the species composition and density of both plants and animals. After fire, there is a shift from chaparral toward open oak-grassland vegetation. Trees are least influenced by burning, with deciduous trees being largely heat tolerant. The digger pine was shown to be most severely reduced. Extensive shrub stands were reduced and invading grasses and forbs increased (Lawrence, 1966).

Although humans have affected the fire regime in southern California and it is believed to have caused some species composition shifts, the overall composition of mid-elevation chaparral does not appear to have changed in the last 70 years in a San Diego study. This may be due to the fact that major shifts are difficult to detect in this short of a time period. A study that re-sampled chaparral plots in San Diego County in 2001, previously sampled in the 1930's, showed very little change in life form composition. Trends could only be detected in mature chaparral. In areas that had 0-1 fires over the entire period, there was a decline in short-life obligate seeders, which is expected because they will not germinate without fire. In areas that had two or more fires, there was an increased abundance of obligate seeders and decrease of obligate resprouters (Franklin, 2004).

The seedling establishment of native chaparral in the first year after fire can be impacted by herbivory (plant-eating animals and insects.) A comparison of the two native chaparral species ceanothus *(Ceanothus greggii)* and chamise *(Adenostoma fasciculatum)* showed that small mammal herbivores prefer ceanothus to chamise seedlings. This herbivore pressure on ceanothus seedlings is enough to tip the survivorship balance in favor of chamise, allowing a relatively higher establishment of chamise seedlings during the first post-fire growing season. In the absence of herbivory, chamise sustains higher mortality. However, herbivory is relatively less important in the survival of chamise seedlings than other causes. Insect herbivory (plant-eating insects) had no effect on either species (Mills, 1983).

Although *small* mammals may prefer ceanothus, another older study focused specifically on the effect of deer browsing on chamise sprouts after fire, showing that deer have a very significant impact on chamise recovery. The impaired recovery of unprotected chamise sprouts was so great, that the researcher recommended use of "exclosures" for deer in any study of California chaparral recovery after fire to exclude the effects of deer browsing (Davis, 1967).

The San Diego Biological Resource Researchers of the San Diego Fire Recovery Network produced an observational summary report of affected flora and fauna in the 2003 wildfires. Chaparral is the predominant vegetation community in the burned areas and consists of several species including ceanothus, scrub oak, manzanita, and chamise. Invasive weed displacement and erosion are the two major risks in post-fire chaparral. Coastal sage scrub is confined predominantly to the coastal regions of southern California and dominated by California sage brush, flat topped buckwheat, and laurel sumac. Although adapted to fire, invasion by weed species can be an issue. Specific areas at risk include south facing slopes in the San Diego River, Harbison Canyon, and Crest areas and the south side and lower slopes of Otay Mountain (San Diego Biological Resource Researchers of the San Diego Fire Recovery Network, 2003).

Post-fire recovery in coastal sage scrub shares some similarities with chaparral, but there are also significant differences. Both are dominated by herbs in the first season after fire and share many of the same herb species. However, the herbs in coastal sage tended to be resprouting perennial herbs versus annual herbs found in chaparral. Both chaparral and coastal sage show rapid regeneration by their resprouts immediately after a fire. However, an overall significant difference in coastal sage is regeneration from soil-stored seeds is low the first season after fire. But the resprouts from the first season will flower and produce seed, and these seedlings will be much greater the second growing season. As in chaparral, slope direction also affected plant growth after fire (Keeley, 1984).

The differences in disturbance history and environmental factors between Los Angeles coastal and inland areas appear to affect plant succession after fire in coastal sage scrub. Los Angeles basin inland areas have a more prolonged grazing history and more air pollution. This is in contrast to the coastal areas that have not been grazed for over a century and have less air pollution due to offshore winds. In addition, coastal areas have cooler summer climates with more frequent fog. The coastal areas showed rapid recovery of herb cover and composition after fire. This is attributed largely to vigorous shrub and subshrub resprouting and the pre-burn presence of native perennial grasses, which resprouted and set seed after fire. In the inland areas, subshrubs did not resprout vigorously after fire, and forbs and vines dominated the first two years after fire due to the lack of native perennial grasses. Exotic annual grasses have also gradually become dominant in these areas, partly a result of low shrub cover and likely due to the prevalent source of seeds from surrounding agricultural areas. Although the reasons for post-fire succession differences between inland and coastal areas cannot be generalized with complete confidence, the regional differences in pollution, grazing, and environmental conditions appear to impact these trends (O'Leary, 1988).

In central coastal California, the native coastal scrub species coyote brush *(Buccharis pilularis* subsp. *consanguinea)* and the annual grass soft chess *(Bromus mollis)* exploit similar disturbed habitats. Interaction between the two appears to show that the coyote brush seedlings suffer from the interference of the soft chess grass seedlings. The two plants have different patterns of seedling development. Preliminary observations indicate that soft chess seedlings initially grow faster and appear to depress the growth of the coyote brush seedlings, an effect that appears to be increased under dry conditions. Whether the interference of coyote brush seedling growth is due to competition for resources or allelopathy (toxic chemicals) from the soft chess was not investigated (De Silva, 1984).

Analysis of Data - Fire Effects on Chaparral and Coastal Sage Scrub

A total of 20 studies are discussed in this section. Wildfire is a major influence in both chaparral and coastal sage scrub with some species even requiring fire as part of their lifecycle. Many research studies have been done on these types of vegetation, although more study appears to have been done on post-fire regeneration of chaparral than coastal sage scrub. The studies did not seem to produce contradicting information. All but three studies appeared in a peer-reviewed journal. The first is the post-fire report completed by the County of San Diego Department of Planning and Land Use (DPLU). The second is the report from the San Diego Biological Resource Researchers, which is a synthesis document based upon informed opinion. The report is a compilation of summaries based on post-fire observations of various floral and faunal communities after the 2003 fires. Eleven authors from local public and private organizations contributed separate sections to this report in their area of expertise. The third source not peer-reviewed is the chapter from the book entitled "Chaparral, and Survival in Southern California."

Numerous factors, which interact and affect each other, have been studied and found to affect succession after fire in chaparral and coastal sage scrub:

- fire factors – fire intensity/heat, ash/char, smoke, amount of time between fires
- physical landscape factors – proximity to the coast, elevation, slope, aspect
- soil factors – moisture, nutrients, pH, allelopathy, soil heating
- mode of reproduction – seeding and/or resprouting
- herbivores (plant-eating animals)

One study stated that aspect, or slope direction, is the most important factor in chaparral succession due to the impact on precipitation and temperature. Another study similarly explained that increased precipitation at higher elevations causes faster chaparral recovery than at lower elevations. Due to the number and interaction of factors that can affect post-fire chaparral recovery, the results observed after different fires at different locations may vary both in plant species composition and rate of return. One serious problem that can occur in both chaparral and coastal sage scrub is the introduction and establishment of invasive grasses when fire intervals are too short. Annual grasses may be more of a problem in places located adjacent to agricultural areas where weed seeds may be abundant. Two studies showed that herbivores, such as deer and small mammals, could impact the post-fire recovery of native chaparral species.

Fire Effects in Desert Ecosystems

The four major deserts in the United States and northern Mexico are generally considered the 1) Great Basin, 2) Mojave, 3) Chihuahuan, and 4) Sonoran, although there are disagreements about how to classify deserts and their exact geographic boundaries. Distinctions between deserts are made on the basis of the species of plants growing in a particular desert region, which is influenced by geologic history, soils, precipitation, and elevation ("North American Deserts," n.d.).

The Web site DesertUSA provides the following information about the desert in San Diego County. The eastern part of San Diego County is desert. A large part of this desert area is California's largest state park, Anza-Borrego State Park. The 600,000-acre park runs 25 miles east to west and about 50 miles north to south. Annual precipitation averages about 6.8 inches. Elevations range from 8,000 feet to below sea level. San Diego County's desert areas are considered to be in the Sonoran Desert, although the California portion of the Sonoran Desert is sometimes referred to as the Colorado Desert ("Anza-Borrego Desert State Park," n.d.).

Discussion of Data – Fire Effects in Desert Ecosystems

Fires occur infrequently in the Sonoran Desert due to limited biomass (plant material), wide spacing between plants, and sparse ground cover. Most of the Sonoran is covered with the long-lived creosote bush scrub *(Larrea tridentate).* Studies indicate that many desert perennials are poorly adapted to fire and succession after fire is very slow, requiring maybe even hundreds of years. Most shrubs after a burn were shown to have limited sprouting and reproduction and were replaced by brittlebush/incienso *(Encelia farinosa)*, native ephemerals, and exotic species. The variation in sprouting of creosote bush scrub observed after various fires appears related to fire intensity. Study results suggest that recurrent fires will select for short-lived shrub species, such as brittlebush/incienso and white bur-sage/burro-weed *(Ambrosia dumosa)*, at the expense of long-lived species like creosote bush scrub (Brown, 1986).

Creosote bush scrub is also common in the Mojave Desert, which is located north of the Sonoran Desert (and San Diego County) and covers portions of southern Nevada and extreme southwestern Utah. It is believed that fire did not occur frequently in creosote bush scrub in warm deserts prior to human settlement, due to the lack of fuels. Human settlement and livestock grazing probably help promote the invasion of annual grasses, such as foxtail chess *(Bromus rubens)*. Although creosote bush scrub is composed mainly of woody shrubs, it is the annual and perennial grasses that fuel the ignition and spread of fire. These grasses can comprise a large portion of the total plant biomass in creosote bush scrub. Increasing fire frequency in the Mojave during the 1980s and early 90's has been attributed to high rainfall in 1983 and 1992 that produced a heavy fuel load of grasses. The USDA Forest Service recommends that fires be suppressed and prescribed burns not be used in Mojave creosote bush scrub because native vegetation responds poorly, which can further promote dominance of exotic species. Livestock grazing might be helpful to temporarily reduce fuels loads from grasses in small areas, but regular grazing over large areas may promote the dominance of exotic species (Brooks, 2003a).

Various levels of vegetative material exist underneath the canopy of creosote bush. The varying level of fuels impacts the peak temperatures that will occur during a fire in this microhabitat. Beneath creosote bushes, lethal fire temperatures occurred for annual plant seeds above and below the ground. At the canopy drip line, lethal fire temperatures occurred only above ground. Lethal temperatures reduced the biomass and species richness of annual plants in following years (Brooks, 2002).

Different annual grasses in the Mojave Desert have different impacts in facilitating the spread of fire. The frequency, cover, and ratio of dead summer vegetation to live spring vegetation was highest for the exotic *Bromus* and *Schimus* grasses in comparison to alien forbs, native grasses, and native forbs. The native forbs were lowest in frequency, cover, and ratio of dead summer vegetation to live spring vegetation. These exotic grasses that thrive in spring become the fuels for summer fires. They enable fire to travel across the "interspaces", or the wide spaces between shrubs and bunchgrasses, which normally hinder the spread of fire in the desert. Fire was found to spread rapidly and continuously across areas with *Bromus* grasses and slowly across areas with *Schismus* grasses (Brooks, 1999a).

Exotic plants evolve in different ecosystems and will invade areas that provide their resources. This can impact patterns of invasion and where exotic plants will most likely be found. The number of species and dominance of exotic annual plants in the Mojave Desert was found to be slightly higher where disturbance was high, and much higher where soil nutrients were high. The exotic *Bromus* grass species were found to be most abundant in desert washlets and on the north side of creosote bush canopies, where nutrient levels were high. Monitoring for the invasion of annual plants should focus on areas of high rainfall and nitrogen deposition (Brooks, 1999b).

The blackbrush plant community in the Mojave Desert is dominated by the species *Coleogyne ramosissimai*, growing at the 4,000 – 5,000 feet elevation range above creosote bush and below sagebrush. Although blackbrush is thought to dominate other shrubs and form nearly pure stands, one study found the number of species in unburned blackbrush to be comparable to other vegetation communities in western North America. Fire reduced blackbrush cover. The number of native plant species and amount of cover decreased, while the number and cover of alien plants increased (Brooks, 2003b).

A 1966 study found the two exotic grasses 1) foxtail chess *(Bromus rubens)* and 2) cheatgrass *(Bromus tectorum)* to be well-established in the "Nevada Test Site," which is located on the boundary of the Mojave and Great Basin Deserts. In the blackbrush vegetation *(Coleogyne)*, foxtail chess was the dominant winter annual, probably due to the similarity of its growth habits and environmental requirements to native winter annual plants. It is a fully integrated member of undisturbed shrub communities. In the disturbed areas, foxtail chess is even more vigorous and grows in denser stands, particularly where the shrubs have been disturbed by fire. In this early 1960's study, foxtail chess was noted not to be aggressive under those conditions. Cheatgrass grows in the higher elevations of sagebrush *(Artemisia)* or the combination ecosystem *Artemisia*-Pinyon-Juniper. It grows on disturbed sites and was noted to be increasing at the time of this early 1960's study (Beatley, 1966).

Managing fire in desert ecosystems creates substantial challenges. Although fires have historically been infrequent in deserts due to lack of fuels, fire was still a natural process in the desert ecosystem. Fire suppression has resulted in fuel buildup that increases fire intensity when a fire does occur. In addition, fires can promote the growth and dominance of exotic species. Prescribed fires can be used to restore a natural fire regime or control invasive species, however, the decision must take into account the effect on invasive plants. In some situations, prescribed fire may not be an appropriate management tactic if fire-tolerant invasive plants are present (Brooks, 2001).

Analysis of Data – Fire Effects in Desert Ecosystems

A total of eight studies are discussed in this section, six of which are produced by the same researcher. Two of this researcher's articles did not appear in a peer-reviewed journal, however, the other six studies that are cited in this paper are all peer-reviewed. Although other studies can be found dealing with other deserts in the United States, these studies were limited to the Sonoran and Mojave Deserts.

These studies show the differences between fire in the desert and other ecosystems such as chaparral/coastal sage and forests. Fire is less frequent in the desert and many perennials, such as creosote bush scrub are poorly adapted to fire. However, fire is still a natural event in the desert and fire suppression allows fuels to build up. Three studies referred to creosote bush scrub, a long-lived perennial that appears to be sensitive to short fire intervals. These studies all emphasized the negative impacts of exotic grasses. A fire interval that is either too short or too long can contribute to invasion of exotic grasses. Use of prescribed fires in the desert must consider the effect on invasive species.

Fire Effects in Forest Ecosystems

Forest ecosystems are also prevalent in San Diego County. Much of the forests are in the mountainous mid-section of the county and located within Cleveland National Forest, which comprises 460,000 acres.

Discussion of Data – Fire Effects in Forest Ecosystems

The County of San Diego Department of Planning and Land Use (DPLU) reported the acreages burned of different vegetation communities after the October 2003 wildfires using the MODIS (Moderate Resolution Imaging Spectroradiometer) fire boundary. A total of 28,109 acres of oak forest and woodland vegetation, 19,937 acres of coniferous forest, and 3,669 acres of cypress forest were burned (County of San Diego Department of Planning and Land Use, 2004).

Similar to his study in chaparral ecosystems, the same researcher does a study in mixed-conifer forests in Baja that shows differences between these forests in Mexico and California. The forests in Baja, where there is no fire suppression, have a more open structure due to infrequent, intense surface fires, occurring approximately every 50 years. These fires are intense enough to kill pole-size and overstory trees. In contrast, fire suppression in California forests has resulted in stand thickening that appears to have reduced the health of the forests. Competition from young trees weakens large trees. Mortality rates are higher for California forests than Baja forests because of drought, bark beetle infestation, and air pollution (Minnich, 2000).

Unnatural fuel buildup is often cited as the cause for large catastrophic forest fires, creating closed-canopy conditions that had previously been open-canopy. This allows surface fires to become crown fires. This idea was originally developed for ponderosa pine ecosystems *(Pinus ponderosa)*. One researcher claims this idea has been incorrectly applied to boreal and sub-alpine forests, which have always been closed-canopy ecosystems and had crown-fire regimes. Fire regime comparisons are made between these types of forests and another researcher's arguments about chaparral, which includes the argument that weather is the driving force behind fire intensity and high-intensity fires burn through all ages of vegetation (Johnson, 2001).

The San Diego Biological Resource Researchers of the San Diego Fire Recovery Network produced an observational summary report of affected flora and fauna in the 2003 wildfires. The oak woodland and oak forest are generally fire resistant, but intense heat may have killed drought stressed oaks. Little old growth coniferous forest likely survived intact on the Cuyamaca Mountains. This is likely due to hot crown fires created by undergrowth trees affected by bark beetle death and competition for water. Fires that burned too frequently in the last 35 years may have eliminated major portions of cypress forest. The burns that occurred through pinyon-juniper woodlands are expected to have been of relatively low intensity, and a limited amount of these woodlands burned in the fire. A wide variety of riparian woodlands burned, including large areas in San Diego River canyon and parts of the San Luis Rey River (San Diego Biological Resource Researchers, 2003).

Analysis of Data – Fire Effects in Forest Ecosystems

Compared to chaparral/coastal sage and desert ecosystems, there is limited data for forest ecosystems in San Diego County. A similar argument regarding fire regimes in chaparral is repeated for forest ecosystems. The first study again contends that fire suppression in southern California forests has the negative effect of allowing vegetative fuels to build up and creates larger fires. The second study argues that weather is the driving force behind fire intensity in boreal and subalpine forests. The report from the San Diego Biological Resource Researchers is a synthesis document based upon informed opinion. The report is a compilation of summaries based on post-fire observations of various floral and faunal communities after the 2003 fires. Eleven authors from local public and private organizations contributed separate sections to this report in their area of expertise. This report is not formally peer-reviewed.

Fire Effects on Wildlife

Animals form an important part of ecosystems. They eat plants and insects and return organic material back to the soil. Although the immediate effects of wildfire on plants are easily observed in a burnt landscape, the wildlife is also directly and indirectly impacted. Some animals die during a fire. Others that depend on a certain habitat for food and shelter must find new homes. Some animals can impact post-fire plant survival by their feeding habits. Similar to many plants species in San Diego County, some of these wildlife species are threatened or endangered.

Discussion of Data – Fire Effects on Wildlife

Exotic plants in desert ecosystems create competition with native plants and contribute to increases in fire frequency. Because desert natives are often poorly adapted to fire, some areas in the Mojave and Colorado deserts have been converted to exotic grasslands that invade after fire. Such plant community changes may also create problems for native animals, such as the desert tortoise *(Gopherus agassizii)*. Certain native plants provide cover and protection for the tortoise from predators and overheating. Exotic grasslands are inhospitable for this animal. Fire can kill by incineration, heightened body temperature, poisoning by smoke, and asphyxiation. Spring fires are more threatening to the tortoise than summer fires as the desert tortoise is more active in the spring. The U.S. Fish and Wildlife Service has listed the Mojave Desert tortoise as "Threatened". Focus on early detection and eradication of new exotic plant species along with law enforcement to minimize human-started fires in the desert is recommended (Brooks, 2002).

Fire casualties in southwestern North America usually focus on birds and mammals. A survey of vertebrate casualties in a desert fire in the Tonto National Forest in Maricopa County, Arizona, found that all resident vertebrates are impacted. The burn was a spotty burn with only half of the shrub cover removed, yet the following dead vertebrates were found: three ground snakes, one coachwhip snake, one side-blotched lizard, one regal horned lizard, and one white-throated woodrat. This is contrary to prior reports that reptiles in the Southwest are not susceptible to fire (Simons, 1989).

Chaparral fire in the Sierra Nevada foothills does not eliminate any species, but there are definite changes in the species composition and density of both plants and animals. (This study is also discussed in the section "Effects of Fire on Chaparral and Coastal Sage Scrub.") Little evidence existed of direct mortality of vertebrates from fire. The woodrat appears to be most vulnerable, due to its house being made of dry twigs. However, lack of cover after the fire presents greater challenges than the fire itself. Populations of most small mammals and some birds decreased after the fire, particularly those that prefer chaparral habitat. Some animal populations did increase. This included: predatory birds and mammals, seed-eating birds, birds that prefer oak-woodland, and an overall increased density of nesting birds (Lawrence, 1966).

A study on the activity of raccoon behavior in oak savanna habitat in east-central Minnesota showed that burned areas do not repel raccoons, nor do they necessarily attract them, either. Tracking of the raccoons showed where the animals traveled four days before the burn, during the burn, and four days after the burn. Of the seven trips made through the area *before* the burn, three trips were classified as “hunting/meadering” and the other four trips as “passing through.” Of the six trips the raccoons made *after* the burn, one trip was classified as hunting/meandering,” and the other five trips as “passing through.” (Sunquist, 1967).

A comparative study on small rodents in southern California burned and unburned grassland and brush habitats measured the recovery of mice populations after a fire. Mice in the unburned grassland area exhibited natural population fluctuations. In the burned grasslands, there was an immediate decrease and generally low density in numbers until the winter of the second year when there was an invasion of mice. In the burned brush habitat, there was also a sharp decrease, but then an increase that surpassed that of the unburned area during the second year after the burn. The actual cause for the initial population decrease after fire is in doubt, although some mice were certainly killed by the fire. There was no evidence to suggest that surviving mice emigrated to adjacent unburned areas. Food in the form of seeds was virtually unaffected by the fire. In both areas, cover seemed to be the restricting force in recovery (Cook, 1959).

A rodent study in coastal sage scrub monitored the response of rodents to fire in order to test the hypothesis that species abundances are largely determined by availability of their preferred resources. MacArthur’s “Q-Minimization” theory is based on this hypothesis and shows mathematically how to predict species composition. This theory was used to predict the post-fire rodent populations of five common species in burned and adjacent unburned areas. The actual results from the *burned* areas corresponded to the predictions. The species composition of the rodents responded to the availability of microhabitats (e.g. rocks, debris, bushes) in a predictable way. However, actual results did not match predictions on the adjacent *unburned* study area. Overall study results were similar to previous studies. Kangaroo rats are associated with open habitats and pocket mice, deermice, and packrats are associated with denser vegetation. The results of this study suggest that MacArthur's theory is potentially applicable (Price, 1984).

A comparative study between burned and unburned coastal sage scrub involving 80 species of birds showed that fire decreased species richness (number of species) in burned areas. The unburned areas provided required habitat elements for more species and individuals and offered a wider range of foraging opportunities. One exception was the flycatchers that preferred the burned area. Numbers of birds in the burned area fluctuated by season during the year, with increased numbers during the spring, indicating that foraging is adequate in burned areas only during the spring. The unburned area was used extensively for foraging while the burned area was used primarily as a resting area. This is in contrast to a previous study in chaparral that showed seed/grain-eating birds prefer burned areas. Higher bird species diversity can be found in burned chaparral rather than unburned in the first two years after fire, which is opposite of the findings in coastal sage scrub. This suggests that prescribed fires may not be advisable in coastal sage scrub (Stanton, 1986).

Fuel-reduction through prescribed burning is a strategy often considered in managing forest ecosystems to prevent catastrophic fires. Fuel-reduction in forests attempts to reduce the shrubs and woody material on the forest floor. This coarse woody material provides habitat for various amphibians and reptiles. Because many amphibian species have declined in the West, it is important to understand their response to fire and fuel-reduction practices. Results from a survey study in the Klamath-Siskiyou region of northern California and southern Oregon showed no preliminary evidence to suggest negative effects of wildfire on terrestrial amphibians. But stream amphibians, such as the tailed frog and torrent salamander, are negatively affected by the elevated stream temperatures and increased sediment loads. Most reptiles are adapted to open terrain, so fire usually improves their habitat (Bury, 2004).

A study in a northern California Douglas-fir forest examined the effect of a slash burn on forest mice to determine if fire could be used to control seed-eating mice, which hinder reforestation. The planned fire killed or drove out all resident mice except those few that stayed in areas not reached by flames. In general, most small rodents waited until the last moment to leave their homes. Mice could not return immediately after the fire due to the layer of ash and cinders that prevented their movement on the forest floor. But after the first rain, the ash and cinder layer was packed down, and an “invasion” of mice began into the burned area. Thus, fire did not reduce the mice population of the area for more than a few days and a slash burn is concluded to be ineffective at controlling mice in a California Douglas-fire region (Tevis, 1956).

The San Diego Biological Resource Researchers of the San Diego Fire Recovery Network produced an observational summary report of affected flora and fauna in the 2003 wildfires. Several butterfly species were impacted by loss of habitat that provided their required host plants. These butterfly species include: Harbison dun skipper *(Euphyes vestries harbisoni)*, Hermes copper *(Lycaena [hermelycaena] hermes)*, Thornes hairstreak *(Callophrys [Mitoura] thornei)*, Quino Checkerspot butterfly *(Euphydras editha quino)*, and Laguna Mountains Skipper *(Pyrgus ruralis lagunae)*. Loss of habitat is also a challenge for many bird species. Impacted riparian bird species include the Southwestern Willow Flycatcher and the Least Bell’s Vireo. Impacted coastal sage scrub/chaparral/grassland mosaic bird species include the California Gnatcatcher, Rufous-crowned Sparrow and the Greater Roadrunner. Raptor species of concern include the California Spotted owl, Bald Eagle, Golden Eagle, and possibly the Burrowing Owl. Impacted wetland bird species include the Light-footed Clapper Rail and Belding’s Savannah Sparrow. Most mammals suffer low levels of direct mortality and use burrow systems or outrun fire to survive. Like other fauna, mammals are also affected by loss of habitat that provides cover and food. Large animals have greater ability to move to new habitats. This will likely result in increased road mortality and increased density and competition in new habitats. Movement of mountain lions may increase human encounters in the near future. Native rainbow trout *(Oncorhynchus mykiss)* may have been impacted by fire heating or evaporating of the isolated water holes in which they reside. The partially armored three-spined stickleback *(Gasterosteus aculeatus microcephalus)*, a freshwater species, may have been reduced in number directly by the fire. Both the trout and stickleback may be affected by stream sedimentation and increased acidity caused by ash deposition (San Diego Biological Resource Researchers, 2003).

Analysis of Data – Fire Effects on Wildlife

A total of ten studies are discussed in this section on Fire Effects in Wildlife. Two studies involve desert ecosystems, five studies involve chaparral/coastal sage scrub/grassland ecosystems, two studies involve forest ecosystems, and one observation study involves a variety of ecosystems. Nine of the ten studies appeared in peer-reviewed journals. The report from the San Diego Biological Resource Researchers is a synthesis document based upon informed opinion. The report is a compilation of summaries based on post-fire observations of various floral and faunal communities after the 2003 fires. Eleven authors from local public and private organizations contributed separate sections to this report in their area of expertise. This report is not formally peer-reviewed.

The desert studies show that fire can directly kill vertebrates and the Desert Tortoise is negatively impacted by loss of habitat. The studies in chaparral and coastal sage showed that loss of habitat, which provides food and cover, is a problem for wildlife in post-fire landscapes. However, research suggests that bird species diversity is actually higher in burned chaparral but the opposite is observed in burned coastal sage scrub. One researcher suggests that prescribed burns may not be advisable in coastal sage scrub due to the negative impact on bird species diversity. The two forest studies did not deal specifically with wildfire. The first study dealt with the impacts of prescribed fires for fuel reduction and the second study used a slash burn to determine if fire could be used to control seed-eating mice that hinder reforestation.

Fire Effects on Soil and Water Quality

Soil and water quality are non-living aspects of an ecosystem that can be impacted by wildfire. Soil erosion can occur due to the removal of stabilizing vegetation that burned away. This can in turn impact an entire watershed and water quality of the streams. Removal of vegetation around a stream can remove shading and allow water temperatures to increase.

Discussion of Data – Fire Effects on Soil and Water Quality

The overall effects of fire on ecosystems include both above and belowground impacts. Impacts belowground include the soil's physical, biological, and chemical processes. Changes can be either harmful or beneficial. The direct effect belowground is a result of the severity of the fire. Low-intensity fires can be beneficial by thinning over-crowded forests and increasing plant-available nutrients. Severe fires often cause negative changes such as loss of nutrients through volatilization, erosion, leaching, and denitrification. Biological disruptions begin in the 40-70 degrees C range. Nearly all soil organic matter is consumed in regions of the soil heated to 450 degrees C. Water repellency is developed in the presence of high-intensity fires of temperatures exceeding 176 degrees C. The overall effect of fire on belowground systems and the resulting effect on aboveground systems are complex and highly variable. Research on this topic is scarce (as of 1999) and more study is needed (Neary, 1999).

An Arizona chaparral study in three small watersheds found that wildfire altered watershed conditions that caused large, though temporary, increases in surface runoff and erosion. Before wildfire there was essentially no runoff for all sites. The first summer after wildfire, nearly every storm caused runoff. Early post-fire vegetation recovery was found to be rapid. Severe flooding and erosion were over in three years. Within five to ten years, stormflows declined to near pre-fire levels (Hibbert, 1985).

The effect of fire on nutrients in a southern California chaparral ecosystem, which includes plants, litter and soil, was studied before and after prescribed fires. Total nitrogen, phosphorus, potassium, sodium, magnesium, and calcium were measured. There were measurable losses of only two nutrients from the ecosystem – nitrogen and potassium. A net loss of nitrogen at the soil surface likely occurred because little was added and some was probably volatized to the air from burning plants. In addition, some nitrogen subsequently was washed away. A total of 11% of nitrogen was lost from plants, litter, and the upper 10 cm of soil when compared to pre-burn levels.   Similarly, potassium was also lost to volatilization through burning, although potassium is not as subject to volatilization as nitrogen. The prescribed fire had little effect on other soil properties in the upper 2 cm, which includes cation exchange capacity and percent sand, silt, and clay (DeBano, 1978).

A literature review on fire's effect on hydrologic and water quality studied both prescribed burns and wildfire in forest and rangeland vegetation types in the Southwest. The extent of fire's effect will depend on the severity of the burn, with prescribed burns at one extreme and wildfires at the other. Prescribed burns usually have less impact because surface vegetation and litter is only partially burned. Vegetation and litter reduce the impact of raindrops at the soil surface by interrupting the fall of precipitation. However, the difference between prescribed burns and wildfire is smaller in chaparral because both types of fire remove the canopy. Prescribed burns in forests do not burn the canopy. In chaparral, wildfires create water-repellant layers in the soil that inhibit precipitation infiltration and cause significant surface runoff. Sediments can be transported with increased runoff. Light prescribed burns will usually have minimal hydrologic impact on watersheds, but wildfires can have a pronounced effect on basic hydrologic processes (Baker, 1988).

A study conducted in a ponderosa pine forest in the Santa Catalina Mountains of Arizona describes the effects of low intensity controlled burning on surface water quality. Runoff samples were collected and measured for calcium, magnesium, sodium, chloride, sulfate, bicarbonate, fluoride, nitrate, pH, total soluble salts, electrical conductivity, and sodium absorption ratio (SAR). Mean concentrations of calcium, magnesium, and fluoride, and the average pH increased following controlled burning. Mean differences in concentrations of other constituents were not significant. Empirical equations were developed to predict changes in sodium, pH, and SAR over time (Sims, 1981).

Natural chaparral regrowth after fire does not happen uniformly. This uneven growth creates vegetation barriers or "buffer strips" along the landscape that capture sediments eroding from uphill sites which are bare. Subsequent fires can remove the chaparral vegetation barrier holding back the sediments, making them susceptible to erosion. However, bare sites still fare worse than sites with vegetation buffer strips. An Arizona study that used aerial photography to track changes in micro-watersheds found that sediment delivery on bare sites was on the average over 300 times larger than on sites with buffer strips. The study also found deposit depths up to 0.45 meters behind buffers strips, which will be at risk for future erosion. This author suggests doing relatively frequent low-intensity burns in chaparral to minimize the potential for a massive fire to cause large-scale movement of sediments. Chaparral buffer strips along waterways could be excluded from prescribed burning to filter sediments from the waterway (Heede, 1988).

A UC Riverside study in the 1960's examined the effect of wetting agents and water repellency on the germination and establishment of ryegrass sown for erosion control. Wetting agents are substances applied to soils that help them to be wetted or absorb water. Water repellant soils literally repel water, or are difficult to wet. This study concluded that water-repellant soils reduce germination potential on slopes by reducing infiltration, which reduces moisture available to the seed. Use of wetting agents may help increase infiltration, increase available soil moisture, and increase germination. Results suggest that in all four soil types used in the study, there were no inherent phytotoxic substances (lethal to plants) which limited germination (Osburn, 1968).

Another study on wetting agents was also conducted in the early 1960's including the same researcher from above that focused on erosion. Surveys of burned watersheds in southern California showed that 60% of the area investigated had water-repellant soils due to changes in the soil brought about by wildfire heat. The results of a study that hand-sprayed wetting agent solution, alkyl-polyoxyethylene, on burned plots showed that the treatment reduces surface runoff and erosion. At that time, the cost of application was about $31 per acre. Other studies show that in southern California, a wetting agent treatment could remain effective for a minimum of one year. Because of the high cost at that time, treatment was recommended only for highly erodible areas. Questions not answered about wetting agents in this study included the most beneficial type of wetting agent, possible detrimental effects to plants and soil structure, and possible hazards of pollution (Krammes, 1968).

A third study in the early 1960's attempted to determine the relationship of the thickness of water-repellant soil layers and the amount of heat that had been generated during wildfire. In unburned chaparral watersheds, the water-repellent layer is most intense where the soil is mixed with decomposed organic material. In burned chaparral watersheds, a water-repellent layer lies below and parallel to the soil surface. The hypothesis for water repellency in chaparral is that a number of chaparral species produce organic materials that can make soils water repellent. During a fire, the heat causes these hydrophobic (repelling water) organic materials to vaporize and move downward in the soil where they condense on soil particles. Results from the study showed that heat applied to experiments moved hydrophobic substances downward and made the underlying sand material water repellent (DeBano, 1968).

A more recent literature review by the same author as above, De Bano, again discusses the role of fire and soil heating on water repellency in wildland environments. The severity of water repellency depends on the combined interactions of soil properties and the soil heating regime developing during a fire. The precise chemical composition of the hydrophobic substances producing water repellency in soils has not been determined. The longevity of a water-repellent condition depends on the severity of the burn. The most practical strategy to ameliorate this condition is to use an effective fuel management program that reduces fuel buildup, which minimizes the occurrence of severe wildfires (DeBano, 2000).

Analysis of Data – Fire Effects on Soil and Water Quality

A total of ten studies are discussed in this section on Fire Effects in Soil and Water Quality. Three of the studies deal with chaparral ecosystems, with two of these addressing erosion issues and the third discussing the effect of prescribed fire on soil nutrients. The most recent of these three study articles was published in 1988. Erosion is acknowledged to be a problem in post-fire chaparral with one researcher suggesting that severe flooding and erosion do not end until after three years and stormflows do not return to normal for five to ten years. Another researcher claims that wildfires can create water-repellant layers in chaparral, which result in more runoff. Light prescribed burns should have minimal hydrologic impact on watersheds, but wildfires may have a significant effect. The study conducted in Arizona ponderosa pine forest found that low intensity prescribed burns increased the mean concentrations of some surface water quality constituents including calcium, magnesium, fluoride, and average pH. Three articles are cited from the late 1960's that were presented at a University of California Riverside symposium on water-repellant soils, and are not peer-reviewed. All three discuss the issue of water-repellent soils created by wildfire heat, with two studies examining the effect of wetting agents to ameliorate the problem. One of the same researchers writes a more recent literature review dated 2000 that again discusses how a water-repellent condition depends on the severity of the burn.

Fire and Structures

The impact of fire to homes and other building structures is often the topic of greatest interest in wildfire discussions, as it involves human safety, property, and possessions. Aspects of fire and construction addressed in this section include interior and exterior wall linings, insulation, fire-retardant treatments, mortar, deck board materials, roofing, overall design, and fire detectors.

Discussion of Data – Fire and Structures

October 2003 Cedar Fire Structure Loss

The County of San Diego Department of Planning and Land Use (DPLU) reported on structure loss that occurred in the October 2003 Cedar Fire. A total of 2,469 residential, commercial, and industrial units were destroyed; a total of 2,766 accessory buildings were destroyed; and a total of 3,516 vehicles, travel trailers, boats, and tractors were destroyed. The overall loss rate of homes within the fire perimeter was 14%. Of the homes built after the 2001 Wildland-Urban Interface code changes, only four percent burned and field inspections indicated that the leading cause was lack of defensible space followed by eave venting and combustible decks. Over 70% of these homes lost had less than 30 feet of defensible space. DPLU concluded the lower loss rate of new homes (4%) built under the County's 2001 Wildland-Urban Interface code changes compared to the overall loss rate (14%) shows the code changes were effective and had a positive effect (County of San Diego Department of Planning and Land Use, 2004).

Interior wall linings

A full-scale burn test of four different wall lining materials that included furnished rooms found the following: 1) 13mm thick painted gypsum board performed the best; 2) 6 mm thick pre-finished fire-retardant plywood was second-best; 3) 6 mm thick pre-finished plywood panels both alone and nailed over 13 mm gypsum board had similar results and performed the worst. Gypsum board wall lining offers better protection than plywood. Properly retardant plywood wall panels offer a significant improvement over non-fire retardant panels (Hirschler, 1998).

A Canadian study was conducted to determine the fire-resistant ratings for wall and floor/ceiling assemblies protected by gypsum board. Gypsum chemically holds water, which enables it to absorb large amounts of heat during fire tests. The amount of gypsum in gypsum board will determine how much heat it can absorb. The ability of gypsum board to provide protection is largely related to its ability to stay in place. Gypsum board is much less likely to fall from wall assemblies during fire tests than from ceilings or floor assemblies. This study carried out a large number of full-scale tests involving different thickness of gypsum board and their installation orientation, use of resilient channels, fasteners and the effects of their placement, effects of glass and rock-fiber insulation, plywood and oriented strand board shear panels, applied loads on joists and studs, blocking and bridging wall and floor assemblies, joist spacing, engineered wood I-joists, metal-plate-connected parallel-chord wood-floor trusses, wall assemblies and char formation in studs, and stud spacing in walls (Richardson, 2001).

A Canadian study characterized building materials according to peak rate of heat release and total heat release, in order to better describe degrees of combustibility. This study was done to provide a different method of describing material combustibility, rather than a simple pass/fail test. Five categories were created from this study. From highest peak rate of heat release and total heat release to lowest, these categories are:

1. Containing PMMA and polystyrene foam insulation
2. Various timber products
3. Fire retardant treated plywood
4. Gypsum boards, concrete slab made with Portland cement and expanded polystyrene beds, concrete slab made with Portland cement, and chemically treated wood particles, glass fiber insulation and proprietary exterior insulation-cladding system
5. Polyplaster slabs, mineral fiber insulation blanket, and ceramic fiber insulation board

(Richardson, 1991)

External Wall Linings

A very similar New Zealand study tested external wall claddings and also characterized them depending on their peak rate of heat release and total heat release. Like the Canadian study, this helps to understand the degree of combustibility of a material, rather than simply categorizing materials as combustible or non-combustible according to a simple pass/fail test. Materials were categorized in three different groups, each containing a specific peak rate of heat and total heat release. In the lowest group were 1) fiber cement board and 2) fiber cement compress sheet (pre-finished). In the middle group were 1) low-density Portland cement-based plaster with polystyrene aggregate, 2) radiata pine with an intumescent paint finish, and 3) exterior insulation and finish system. In the highest group was were 1) extruded twin-wall uPVC weatherboard, 2) foamed cellular uPVC weatherboard, 3) unfinished radiata pine, 4) stained radiata pine, and 5) acrylic paint finish radiata pine (Wade, 1995).

Insulation

A German study compared foam-based insulated exterior wall systems with mineral-based exterior wall systems. In the foam-based system, which included expanded polystyrene insulation 80 mm thick with a density of 15 kg/m^3, the fire intensity increased due to the melting and burning of the insulation materials. The mineral-based system, which was 80 mm thick with a density of 150 kg/m^3, performed much better than the foam-based system (Christensen, 1995).

A Canadian study tested the impact of two subfloor types and the insulation type and thickness on fire resistance of small-scale floor assemblies. The effect of subfloor type, either Canadian soft plywood or oriented strand board, on fire resistance was found to be insignificant. The effect of glass fiber insulation thickness was insignificant for both solid wood and steel C-joist assemblies, but significant for wood I-joist or parallel-chord wood trusses. For all the assemblies, the installation of rock or cellulose fiber insulation in the floor cavity increased the fire resistance compared with a non-insulated assembly. The installation of glass fiber insulation in the floor cavity increased fire resistance for all assemblies, except the parallel-chord wood truss, which actually had reduced fire resistance (Sultan, 2000).

Decks

The University of California Fire Research Laboratory did a study to develop test protocols and test the performance of plastic, wood-plastic, or solid wood deck board materials. Materials were subjected to both an under-deck and above-deck fire. Results showed that cross-section form (solid, hollow, or channeled), regardless of material affected performance. Channeled products did poorly in under-deck fires and hollow products performed poorly in above-deck fires. Solid redwood, a common deck material in California, performed as well as any other materials tested in both under- and above-deck fires. Fiber reinforcement was also found to improve the fire performance of the polyethylene-based decks (Quarles, 2003.)

The National Building Code of Canada (NBCC) has required fire resistance ratings for buildings and simple calculation methods for figuring fire-resistance ratings of heavy timber beams and columns. However, the NBCC does not provide methods for calculating fire resistance of timber floor decks. Instead, they provide specific construction specifications for floor decks to meet fire resistance ratings. These specifications work for new construction, but may not be possible to implement in renovations, such as for historic buildings. This Canadian study was conducted to test the fire resistance of various combinations of different ceiling/floor coverings on timber decking that have been found to commonly have gaps (2-4mm) due to shrinkage as a result of drying out. Gypsum wallboard installed on the underside of a timber deck will provide 18-20 minutes of thermal protection. When either 15 mm thick plywood or oriented strand board (OSB) was fastened to the top of 38 mm thick lumber having flat butt edges and 4 mm wide spaces between the boards, 50 minutes of thermal protection was provided (Richardson, 2001).

Fire Detectors

Four different types of fire detectors were tested to assess their sensitivity and response times. The four types were: 1) ionization smoke, 2) optical smoke, 3) infra-red, and 4) rate of heat rise detectors. Results showed the infra-red detectors have the quickest response in high-temperature flaming fires and were good for detecting non-smoking fires. The optical smoke detector was good for detecting slow smoldering fires. The ionization smoke detector could only detect fires with smoke, but not clean fires. The rate of heat rise detector responded only to fires of high temperature (Chow, 1994).

Fire Resistance and Fire-Retardant Treatments (FRT)

A Canadian study investigated possible ways of increasing the fire resistance of wood timbers by using some proprietary [in 1987] flame-retardant paint and coating systems. Thirty North American paint and coating products were applied to one face of Douglas fir tongue-and-groove plank. Char formation under the two fibrous coatings was reduced by 50-85%. There was no char formation under either of the cementitious coatings. The insulative nature of the intumescence, or swelling of the coating film when exposed to high temperatures, created by some of the flame-retardant coatings substantially reduced the temperature of the wood directly under the coatings. After 30 minutes of fire exposure, some retardant coatings reduced char formation by nearly 70%. It is confirmed that the mechanism by which the coating affected char formation was exclusively by imposition of an insulative thermal barrier between the wood and the fire, not by a chemical reaction with the wood. Neither the polyurethane nor the epoxy type flame-retardant coating systems were as fire resistant as many of the intumescent paint products (Richardson, 1987).

A 2001 literature review overviewed the available literature on the durability of FRT wood in exterior and humid conditions and also identifies the lack of information and research. The only available information on durability of FRT wood products at humid and exterior conditions is based on American standards for accelerated ageing and for fire testing, which do not include freezing conditions and only partial exposure to ultraviolet radiation. There is a lack of experience on the correlation of these accelerated ageing methods and natural field testing. No comparisons between the exposures of FRT wood in different climates have been performed. There is a need for procedures to evaluate the durability and service life predictions of FRT wood that also considers cost and time effectiveness (Östman, 2001).

A Japanese study tested the difference in fire resistance by adding different size sheets of graphite phenolic sphere over the metal plate connectors at the butt joints of laminated veneer lumber. The graphite phenolic sphere sheeting protects the surface of a joint directly exposed to fire by preventing rapid deflection. Time to rupture increased with the size of the sheet. The most significant results were seen when all three sides were covered. Protecting the joint solely on the bottom also improved rupture time, however, protecting the sides without the bottom did not have any remarkable effect (Subyakto, 2001).

Mortar

Fiber reinforcement is used to improve the brittle characteristics and easy breakability of hardened cement pastes. Fibers affect the microstructure of concrete or mortar, which then affects its fire behavior. A small-scale test using 35 mortars with nine different types of fibers found that fibers affect the release of moisture from the fiber mortar material. Incorporating fibers can reduce local pressures caused by water vaporization, due to rapid heating as in the case of fire. The effect of fiber dosage by weight on the thermal properties of fiber mortar composites is relatively small. However, fibers have a weak insulating effect. Temperature and mass loss measurements of dried specimens under thermal exposure show no differences between fiber mortars containing different fibers. Use of polyacrylonitrile fibers in mortar may increase the risk of spalling (breaking off in chips or layers) under rapid thermal exposures due to fire, but more testing is needed to validate this particular statement (Sarvaranta, 1994).

Design

A University of California Fire Research Laboratory study examined how some wood frame construction design details commonly used to provide moisture protection may conflict with the details used to provide fire protection. These details are particularly important in homes built in the urban-wildland interface where both moisture and fire protection are important.

Common examples of conflicting designs include attic and crawlspace ventilation and roof overhangs. Ventilation can allow flames and embers to enter, but are important in climates where moisture is a concern. Narrow overhangs provide more protection from flames and embers, but are not as efficient in protection against rain. In decks, gaps improve drying potential after rain, but gaps allow for flame impingement. For homes built in the urban-wildland interface, it may be necessary to make tradeoffs to provide more fire protection but not at the expense of making the structure overly vulnerable to moisture (Quarles, 2002).

Roofing

Since residential roof fires remain a life-threatening danger to homeowners in the United States, an article written by medical professionals appeared in a scientific medical journal on a national fire prevention program for reducing roof fires. This program uses a system developed by Underwriter Laboratories Inc. (UL) and the National Fire Protection Association (NFPA). UL developed a standardized way early in the twentieth century to evaluate roof coverings that assigns three fire ratings, A, B, or C. Class A roof coverings provide the most protection. California legislature requires the use of a Class A roof system, but this is not the case everywhere in the United States, even though Class A roof systems using fiber-glass-based asphalt shingles are widely used. The program outlined in this article helps homeowners to ensure a Class A roofing system is installed (Edlich, 2004).

Sprinklers

A Japanese study tested the physical properties of sprinkler spray by using two types of commonly used commercial sprinkler heads: 1) Globe Conventional Pendant Sprinkler of 15 mm orifice, and 2) Globe Spray Pendant Sprinkler of 15 mm orifice. Increasing the flow rate of water and pressure will increase the spray diameter and volume of the water cone. The height of the sprinkler will affect how the water is distributed on the floor and is different for the two types of sprinkler heads. Optimal droplet size for fire extinguishments is around 4-5 mm in a large fire. In this study, all the conditions produced water droplets below 3 mm in diameter which is regarded as either ineffective for penetrating the fire plume or not very efficient in cooling the ambient atmosphere (Chow, 1993).

An Australian study proposes how to optimally control sprinklers in compartment fires, which are defined as fires in enclosed spaces such as rooms in buildings. Optimal control is based on the need for the sprinkler to activate and adequately put out the fire without running too long and causing water damage that would exceed flame damage. The mathematics behind the idea of optimal control are provided in this study. The researchers propose using a sprinkler head with a solenoid valve connected to a computer that will continue spraying water only until the fire is extinguished (Hasofer, 1997).

Analysis of Data – Fire and Structures

A total of 18 studies are discussed in this section on Fire and Structures. The first study is a post-fire report from the October 2003 Cedar Fire by the County of San Diego Department of Planning and Land Use (DPLU) that was not peer-reviewed. DPLU concludes the lower loss rate of new homes (4%) built under the County's 2001 Wildland- Urban Interface code changes compared to the overall loss rate (14%) shows the code changes were effective and had a positive effect. The report also noted the importance of adequate defensible space around a structure.

Much of the remaining section focuses on construction standards, testing, and test protocols, and involves technical data likely of most interest to the construction industry. Testing is done on building materials to evaluate their reaction to fire. In some cases, even the test protocols themselves are tested. It should be noted these tests were necessarily performed in laboratory situations and are not the results from actual wildfires. In addition, studies were included in this section addressing interior situations and components that may have limited applicability when discussing wildfire preparedness.

The test protocols used for much of the research referred to in this section come from ASTM International, originally known as American Society for Testing and Materials. This is a not-for-profit standards organization, which focuses on developing voluntary codes and regulations for global use in technical materials, products, systems, and services. Many of the research articles appearing in a scientific journal from this section were found in *Fire and Materials,* an international journal directed at the fire properties of materials and the products into which they are made. Much of the research is international, with many studies coming from Canada. Other countries include Germany, Japan, New Zealand, and Finland.

Defensible Space

Defensible space can be described as the area or space around homes and buildings where vegetation and other factors are managed for a specific distance to keep fire at a point where it cannot ignite the structure. This managed area or space literally provides a "defense" against the fire to reduce the structure's exposure to flame radiation (heat), flame impingement, and firebrands (burning embers), which are considered the three principal factors in igniting a fire.

Discussion of Data – Defensible Space

A USDA Forest Service study created a program called the Structure Ignition Assessment Model (SIAM) to analytically determine the potential of any structure to ignite. This risk assessment is based on a worst-case estimate of the direct effect of flames as well as burning embers. One initial conclusion of the SIAM model is that tempered glass is superior to plate glass in avoiding window breakage that will allow fire to enter a house (Cohen, 1995).

The SIAM model was later used in another USDA Forest Service study to estimate the potential for structure ignitions using various types and densities of vegetation and different flame-to-structure distances. Radiant heat flux from burning vegetation, or the transfer of heat from flames to structure, is a principal factor in igniting a structure. Radiant heat flux depends on the size of the flame front, the distance from the structure of the flame front, and the duration of the radiant flux. Thinning and/or removal of vegetation, including trees, will decrease the size and duration of the flame front. Increasing the distance between a structure and surrounding vegetation will increase the distance from the flame front. Heat flux can also be blocked by unburned (non-combustible) vegetation. Model results showed that the flame radiation from vegetation burning beyond 40 meters of a structure is unlikely to ignite a structure on fire. Thinning vegetation within 40 meters of the structure has a significant effect (Cohen, 1996).

The same USDA Forest Service researcher again concludes in later work that effective fuel modification to reduce wildland fire losses only needs to occur within a few tens of meters from a home. This indicates that effective residential fire loss mitigation must focus on the design and materials of a home and its immediate surroundings, or the concept of "home ignitability." When identifying wildland-urban interface fire problem areas, home ignitability must be the principal mapping characteristic rather than a geographical location in relation to wildlands. Although extensive wildland vegetation management may serve a purpose, it will not effectively change the level of ignitability of a home. Homeowners must take the principal responsibility for ensuring low ignitability of their homes, rather than solely rely on fire services for fire protection (Cohen, 1999). In another literature review on how to prevent residential fire disasters during wildfires, this researcher writes that flames must be at a distance closer than 30 meters for direct ignition to occur, but firebrands can ignite a structure from greater distances. Therefore, in order to sufficiently protect the house, vegetation should be managed within 40 meters and the house should use noncombustible exterior materials (Cohen, 2000).

This same researcher tests the reliability of his model under test fire conditions, acknowledging that the model produces worst-case estimates for fire threat distance in wood structures. Plots of land were set on fire upwind from wall structures ten meters in size built out of untreated and unpainted plywood with a small roof section made of oriented strand board. These experimental crown fires did not transfer sufficient heat to meet combustion requirements for the wood walls at distances beyond ten meters, partly due to the short duration of the experimental crown fire flaming. In comparison, the model overestimated the distance that the walls would ignite with figures closer to 30 meters. However, the experimental fires did not present the conditions that can occur during extreme wildland fires and the model estimates should continue to be used for practical application. The experiment also showed how shading from trees and eaves reduces radiation heating. Both this experiment and the model used for comparison show that the distance required for flame heating that leads to wood wall ignition is on the order of a few tens of meters (Cohen, 2004).

Another USDA Forest Service researcher shares some of the same themes in a literature review that appeared in a peer-reviewed journal. Managing the wildland-urban interface is the responsibility of homeowners as well as public land managers. Local governments need to officially recognize the problem of fire-prone construction in its planning and budget efforts. The question of who should pay for adequate fire protection – the community, homeowner, or the developer – should be resolved to create more accurate insurance rate structures. Priority must be placed on effective methods of communicating with the public and policy leaders to avoid making bad land development decisions in relation to fire protection (Davis, 1990).

A literature review from the Center for Biological Diversity repeats the ideas that protection in the wildland-urban interface depends on protecting the house itself and the area around it. In this case, 60 meters is suggested versus 40 meters to provide a safety margin to account for steep slopes or tall trees that could produce scorching of exterior walls. Continuous fuels that lead from the forest to a home should be eliminated by using rock landscaping, cement sidewalks, green grass, or raking away needles and dried vegetation. The flammability of a house itself should be reduced through use of fire-resistant materials and removing dead vegetation from roofs and gutters (Nowicki, 2002).

The Defensible Space Factor Study (DSFS), initiated in 1989 by the California Department of Forestry and Fire Protection (CDF), collects information on wildland fires where structures have been lost or threatened. In 1990, the DSFS did a major statewide data collection effort on 1,500 structures threatened, damaged, or destroyed by wildfire. In the long term, this data would be used to identify which measures in building construction, site maintenance, and defensive action are most effective in reducing a home's vulnerability to fire. Most observations and preliminary results of this study were consistent with previous studies. The difficulty in accurately quantifying some types of data, such as vegetation clearance and hazard, is also described. One clearance distance for all types of vegetation is not sufficient to characterize fire hazard, as different wildland and ornamental vegetation types vary in the fuel potential and fire hazard they present. Although the most useful information is obtained from the remains of wildland fires, the survey instruments, trained personnel, and organizational framework must be in place before work begins on major incidents (Foote, 1991).

An Australian study examined the data from three historical fires in Australia to quantify the penetration of bushfires into urban areas. One of the fires was a pine forest fire and the other two fires were eucalypt bushland fires. The maximum distance at which homes were destroyed was typically found to be less than 700 m (675 yards), with 145 meters the median distance (158 yards). The relationship between homes that were destroyed and the bushland-urban boundary was found to be a simple linear and decreasing function of distance. The slope of this decreasing linear line varied, likely dependent on fire regime and human intervention. The probability of home destruction at the fire edge in the first 50 meters (55 yards) was around 60% (Chen, 2004).

An online database from the University of California Forest Products Laboratory (UCFPL) compiles fire performance ratings of residential landscape plants. This is a referenced database, with at least three references for each recommendation. Plant species are categorized broadly with either a favorable or unfavorable fire performance rating ("Defensible Space," n.d.).

Analysis of Data – Defensible Space

A total of ten studies are discussed in this section on Defensible Space. Five of the studies are by the same USDA Forest Service researcher with three of his reports appearing as publications for the USDA, which are not peer-reviewed. Two of the more recent studies did appear in peer-reviewed journals. All five studies essentially repeat the same theme that vegetation management is necessary in approximately the 40 meters (44 yards) around a structure to prevent direct ignition from flames. Using noncombustible exterior materials is necessary to prevent ignition from firebrands (burning embers) that may come from further distances. This researcher contends that the homeowner has a primary responsibility in protecting their residence. A second USDA researcher repeats the ideas of homeowner responsibility and adds that the public and policy makers need to be informed to avoid making bad land use and zoning decisions that hinder fire protection.

Other defensible space and fire threat distances are referred to in other studies. A literature review from the Center for Biological Diversity suggests 60 meters (66 yards) versus 40 meters (44 yards) to provide a safety margin to account for steep slopes or tall trees that could produce scorching of exterior walls. An Australian study on three large historical fires found that the maximum distance at which homes were destroyed was typically found to be less than 700 meters (675 yards). In two of the fires, the residential area was located at least 40 meters from the bushland, which might seem to significantly contradict a recommended distance of 40 meters for defensible space. However, floating embers in severe, windy fire conditions were suggested to be the cause of ignition in these two fires. This study also does not examine the construction and building materials of the residences that were burned, nor the vegetative material located adjacent to these homes. One relatively stable statistic for all three fires in this study was that 60% of all homes located within 50 meters of the bushland were burned. This suggests that the majority of damage, even in severe fires, is done within this distance.

Post-fire Restoration Practices

After a disturbance such as wildfire, efforts are often undertaken to minimize the potential negative effects on the environment such as erosion, loss of habitat, and invasion of exotic species. There is often a desire to have the burned area returned to its pre-fire condition.

Since many burned areas were not considered natural, returning them to a more "natural" state is sometimes the goal.

Discussion of Data – Post-fire Restoration Practices

Although the definition of ecological restoration is not clearly defined, one author argues the definition of good ecological restoration must include historical, social, cultural, political, aesthetic, and moral aspects. Much restoration practice work focuses on technological activities and projects that do not achieve ecological fidelity. The author describes ecological fidelity as based on three principles: 1) the restored ecosystem must strongly resemble the structure and composition of the so-called natural ecosystem, 2) the restored ecosystem can function successfully and 3) the restored system has durability (Higgs, 1997).

A lengthy USDA report evaluated the effectiveness of post-fire rehabilitation treatments covering 321 projects from 1973 through 1998 in the western United States. Treatments were divided into three categories: 1) hillslope, 2) channel, and 3) road treatments. For many treatment methods, effectiveness could only be determined qualitatively as quantitative data was available for relatively few treatments. For hillslope treatments, mulching and geotextiles were rated the most effective because they provided immediate ground cover to reduce raindrop impact and hold soil in place. However, both methods are costly and are difficult or impossible to install in remote locations. Contour-felled logs also provide immediate benefits because they trap sediment during the first post-fire year, which usually has the highest erosion rates. Road failures can be prevented with treatments such as properly spaced rolling dips, water bars, and culverts. Channel treatments should be used sparingly as onsite erosion control is more effective than attempting to catch and store sediment in the channels. This study concluded that rehabilitation should be done only if the risk to life and property is high, since the amount of protection provided by treatments is small. In some watersheds, it would be best not to do any treatments (Robichaud, 2000).

A variety of erosion control measures were implemented on critical areas within the urban interface following the southern California fires of 1993. These Best Managements Practices (BMPs) were intended to provide immediate dust control and temporary soil stabilization until permanent vegetation could become established. Observations and evaluations were conducted in Laguna and Malibu, CA, by private consulting firms. The study showed that temporary erosion control measures, such as mulches, binders, and matrices, have no negative long-term effect on natural regeneration of native plants, both from root systems and dormant seeds. There appeared to be no significant difference in vegetation re-establishment between areas treated or untreated with erosion control. Although vegetation will re-establish itself with or without erosion control, it does not grow fast enough to provide stabilization the first rainy season after fires. Temporary erosion control provides protection until permanent vegetation cover becomes established (Harding, n.d.).

A study done in Riverside, CA, evaluated five treatments on burned coastal sage scrub sites to determine the most effective method to restore native shrublands by reducing available nitrogen in the soil and minimizing competition from exotic annual grasses. Competition from exotic grasses was reduced by hand cultivation and herbicide. Bark mulch was applied to tie up and immobilize nitrogen in the soil. Reseeding of native species was done with a mix of California buckwheat, California sagebrush, monkey flower, white sage, black sage, bush mallow, and bush penstemon. There was no native seedbank left at the site after approximately 30 years of conversion to annual grassland. Seeded shrubs established only in the hand cultivated and herbicide treated plots, which removed competition from weeds. Seeding was also only successful in a wet year and unsuccessful in a dry year. The mulch treatment neither decreased exotic grasses nor increased native shrub establishment (Cione, 2002).

A study done in Temecula, CA, at the Santa Margarita Ecological Reserve also evaluated exotic grass competition in native coastal sage shrub restoration. The conversion of shrubland to grass land is typically associated with disturbance caused by intense grazing, high fire frequency, or mechanical vegetation removal. The species, *Artemisia californica*, is the most common overall species of coastal sage scrub. It grows with a relatively low and open canopy structure that allows for a persistent herb layer. The Mediterranean exotic grasses are composed mainly of species in the genera *Avena* and *Bromus.* These are among the species that have replaced native plants throughout California to form the California annual types. This study showed that stands of these Mediterranean annual grasses have a competitive edge over seeded *Artemisia,* from germination through the first growing season. By the end of the second growing season, when the seeded *Artemisia* were sixteen months old, the effect of grass density on *Artemisia* biomass had diminished. Planting *Artemisia* seedlings instead of seeds would bypass the critical period for survival and have a 20-40% greater chance of survival, even in the highest grass densities (Eliason, 1997).

A 2001 literature review studied the influence of space and time on habitat selection. It is argued that to successfully provide habitat for wildlife, these influences must be considered. Habitat is not static but changes over time due to natural and human disturbance. When attempting to restore habitat for wildlife, the following recommendations should be followed: 1) identify the wildlife species target for restoration, 2) consider the size and landscape context for the restoration site and whether it is appropriate, 3) identify the habitat elements necessary for the target species, 4) develop a strategy for restoring those elements and the ecological processes that maintain them, and 5) implement a long-term monitoring program to gauge the success of the restoration efforts (George, 2001).

A literature review summarized the effects of fire on the soil resource in Arizona chaparral, including physical, chemical, and biological soil properties. These effects were used as a basis for discussing short and long-term consequences for post-fire rehabilitation. Some important considerations in rehabilitation are losses of total nutrients, changes in nutrient availability, decreased infiltration, and subsequent erosion on burned areas. Nitrogen is the most important nutrient lost because it is lost in the largest quantities and most likely to be the most limiting nutrient in chaparral ecosystems. Although there is an initial "flush" of available nitrogen after a fire, these levels drop after a year. Mechanisms available for restoring nitrogen lost during a fire include: input by bulk precipitation, nitrogen-fixing plants, and microorganisms. Bulk precipitation is substantially greater in metropolitan areas that have nitrogen pollutants in the atmosphere. If seeded grasses are used for erosion control, care must be taken that they do not compete or interfere with nitrogen-fixing shrubs, such as *Cercocarpus* sp. and *Ceanothus* sp. The usefulness of grass reseeding for reducing post-fire erosion has not been clearly established. This literature review found that most research indicates that fertilization immediately following a fire is not a recommended practice. Prescribed fires are recommended to reduce the potentially catastrophic wildfires that have greater impacts on the soil (DeBano, 1988).

The San Diego Biological Resource Researchers of the San Diego Fire Recovery Network produced an observational summary report of affected flora and fauna in the 2003 wildfires. Post-fire management and restoration recommendations were included in this report.

In coastal sage scrub, monitoring and removal of weedy species is necessary to avoid displacement of scrub. Chaparral will need erosion control in specific key locations, especially on Gabbro soils. Oak woodlands will require re-vegetation that includes direct seeding and planting of container stock. Coniferous forests will require thinning of dead trunks in some locations to allow regeneration of new seedlings. Cypress forest may require manual replanting in some areas using local seed source. Limiting future fires in both the Cuyamaca Cypress and Tecate Cypress areas for the next three decades is vitally important. No special treatments are needed in pinyon juniper woodlands. Riparian woodlands will need to be monitored and managed for removal of tamarisk, arundo, and other invasive species (San Diego Biological Resource Researchers, 2003).

<u>Analysis of Data – Post-fire Restoration Practices</u>

A total of eight studies are discussed in this section on Post-fire Restoration Practices. Each deals with a slightly different aspect or issue of post-fire restoration. The first study attempts to define what good ecological restoration should involve and suggests that historical, social, cultural, political, aesthetic, and moral aspects should be considered as well as technical aspects. This article may provide some useful suggestions for overall planning and analyzing of restoration projects.

Two articles deal with post-fire erosion control measures, the first analyzing the erosion control effectiveness of different treatments and the second evaluating the effect of erosion control of native vegetation regeneration. Although the USDA report, which is not peer-reviewed, could only produce qualitative data for many of the treatments, the fact that a large number of actual projects (321) were reviewed should give this study some validity. This study concluded that rehabilitation should be done only if the risk to life and property is high, since the amount of protection provided by treatments is small. The second study examined the effect on vegetation regeneration and found that temporary erosion control measures, such as mulches, binders, and matrices, have no negative long-term effect on natural regeneration of native plants. Although vegetation will re-establish itself with or without erosion control, it does not grow fast enough to provide stabilization the first rainy season after fires.

Two studies on coastal sage restoration projects show the problems presented by competition from exotic grasses. In the first study, the successfully reseeded plots were only in the hand cultivated and herbicide treated plots. Although this may work well for research purposes, hand cultivation and herbicide treatment to control weeds would be extremely difficult on a large scale. In addition, seeding was also only successful in a wet year and unsuccessful in a dry year. The second study suggests that the survival of *Artemisia californica,* a common coastal sage species, can be improved by planting seedlings instead of seeds in restoration projects where annual grasses are a problem.

A study on wildlife habitat restoration suggests that the factors of space and time must be considered and makes practical suggestions for doing a wildlife habitat restoration project.

The final study addresses the impact that post-fire soils in chaparral may have on plant rehabilitation, particularly the impact of lost nutrients. Although this source is not peer-reviewed, this particular author is cited in two other peer-reviewed articles in this paper. This study refers mostly to Arizona chaparral, but comparisons and references are made in the article to California chaparral. One specific post-fire recommendation is to take care that restoration practices do not interfere with the regeneration of nitrogen-fixing shrubs that will provide a source of the nitrogen that will be in short supply.

The report from the San Diego Biological Resource Researchers is a synthesis document based upon informed opinion. The report is a compilation of summaries based on post-fire observations of various flora and faunal communities after the 2003 fires and also includes some recommendations. Eleven authors from local public and private organizations contributed separate sections to this report in their area of expertise. This report is not formally peer-reviewed.

Other suggestions for post-fire restoration provided by studies discussed in other sections in this paper include the following:

1) Non-dormant domesticated California poppy *(Eschscholzia californica)* seeds are not appropriate for post-fire restoration, particularly in environments that naturally support plants with dormant seeds (Montalvo, 2002).

2) A slash burn is concluded to be ineffective at controlling mice that hinder reforestation in a California Douglas-fire region (Tevis, 1956).

3) The annual ryegrass *Lolium multiflorum,* which is commonly seeded in southern California post-fire landscapes, was found to average only 3.4% cover on study sample sites that had been aerially seeded a few weeks after fire in burned chaparral and coastal

sage scrub (O'Leary, 1988). When ryegrass does manage to successfully establish, it has been reported to interfere with shrub recovery (Biswell et al., 1952, Gautier, 1982, as cited in O'Leary, 1988) and native chaparral herb establishment (Keeley et al, 1981, as cited in O'Leary, 1988).

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