Appendix C

Fire Effects Monitoring and Research Plan

for the 2004 Fire Management Plan for Mojave National Preserve

<u>Contents</u>:

1.0 Overview of the Fire Ecology of Mojave Desert ecosystems

The U.S. Geological Survey recently published a vegetation community map for the central Mojave Desert, including Mojave National Preserve. Maps were based on a 5 hectare minimum mapping unit and map polygons were classified based on photo interpretation of 1:32000 aerial photography, predictive modeling, field observations, geomorphic landform and surface composition GIS, and expert knowledge (Thomas et al. 2004). Vegetation types were identified to the alliance level thematic resolution based on the National Vegetation Classification System (FGDC 1997).

Using this vegetation map as a starting point, each polygon was then assigned to one of the major ecological zones described by Brooks and Minnich (in press) based on described vegetation and elevation. These assignments were not specifically verified in the field, but do reflect commonly recognized changes in vegetation as recognized in the field.

Table D1. Crosswalk of each "system" field of the vegetation map (K. Thomas et al 2004) assigned to "ecological zones" of fire ecology (Brooks and Minnich in press).

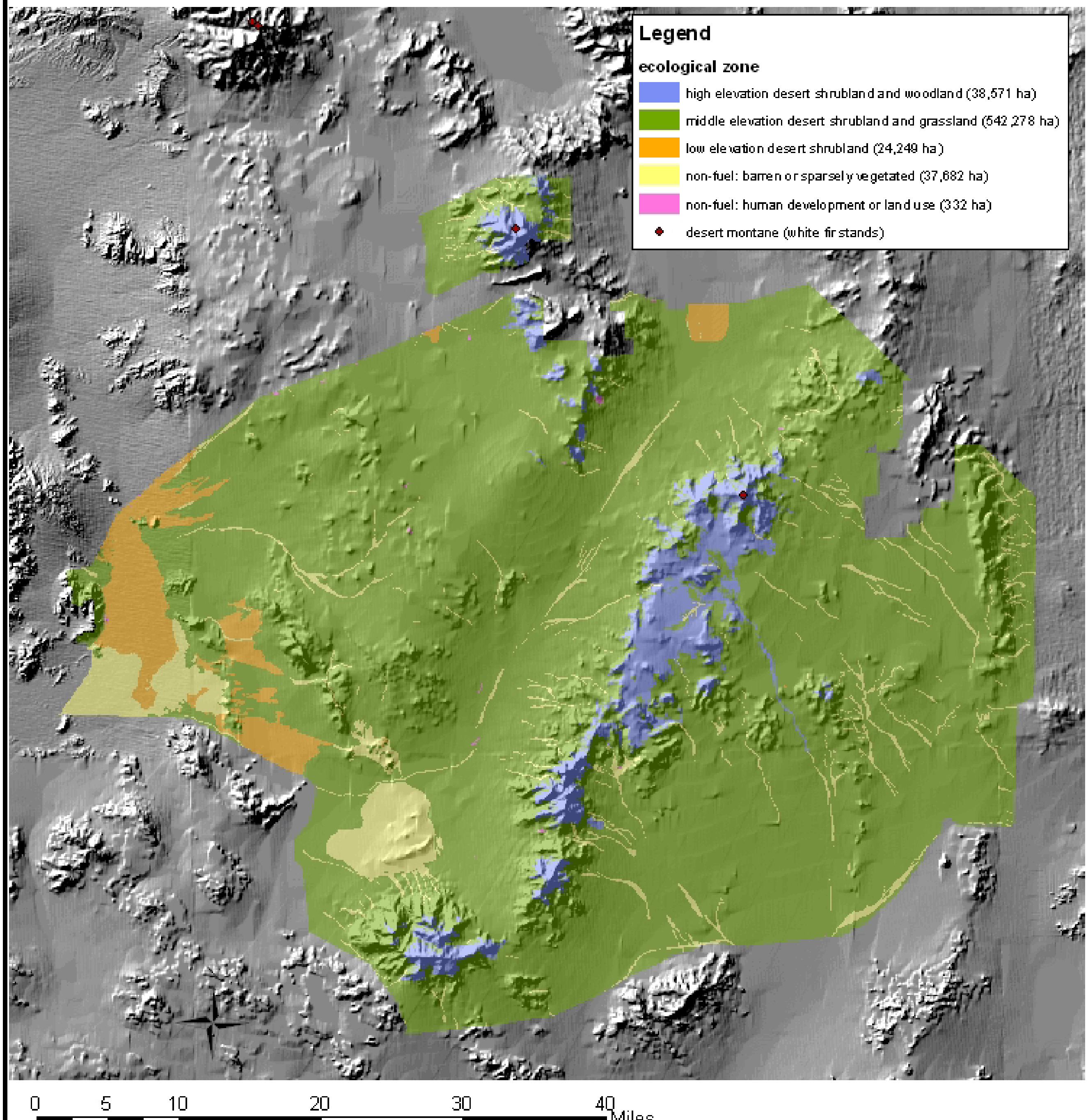
Vegetation Map system	Assigned Ecological Zone
Creosote Bush Mixed Shrubland w/ saltbush label	Low Elevation Desert Shrubland
Creosote Bush Mixed Shrubland	Middle Elevation Desert Shrubland or Grassland
Creosote Bush Mixed Shrubland w/ juniper label	High Elevation Desert Woodland and Shrubland
Desert Grassland and Shrub Steppe	Middle Elevation Desert Shrubland or Grassland
Desert Sink	Low Elevation Desert Shrubland
Desert Wash System	Non-fuel: barren or sparsely vegetated
Desert Wash System w/ Mojave yucca, blackbrush, or Joshua tree label	Middle Elevation Desert Shrubland or Grassland
Interior Dunes	Non-fuel: barren or sparsely vegetated
Interior Dunes w/ galletta grass label	Middle Elevation Desert Shrubland or Grassland
Land Use	Non-fuel human development or landuse
Land Use w/ Joshua tree or blackbrush label	Middle Elevation Desert Shrubland or Grassland
Lava Beds	Middle Elevation Desert Shrubland or Grassland
Mid Elevation Mixed Desert	Middle Elevation Desert Shrubland or Grassland
Mid Elevation Mixed Desert w/ juniper, pinyon, or sagebrush label	High Elevation Desert Woodland and Shrubland
Mid Elevation Mixed Desert w/ saltbush label	Low Elevation Desert Shrubland
Pinyon Juniper Woodland	High Elevation Desert Woodland and Shrubland
Pinyon Juniper Woodland w/ Joshua tree, Mojave yucca or blackbrush label	Middle Elevation Desert Shrubland or Grassland
Saltbush Scrub	Low Elevation Desert Shrubland
Barren	Non-fuel: barren or sparsely vegetated

Mojave National Preserve
California
Fire Management Plan

National Park Service
U.S. Department of the Interior

Figure D1: Ecological Zones

The vegetation was mapped by the U.S.Geological Survey and the map units were classified based on the National Vegetation Classification System (Thomas et al 2004). For analysis of fire ecology in Mojave National Preserve, each polygon was assigned based on vegetation and elevation to one of the major ecological zones described by Brooks and Minnich (in press). The classification into ecological zones was completed by Park Biologist S. Dingman.



Produced by S. Dingman, Biologist, Mojave National Preserve **July 2004**

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A synthesis of fire ecology literature is the foundation of any fire effects and research program. A review of fire related literature found that while there are several useful publications published in the last 15 years, in general, there is little known about the behavior and effects of fire in the Mojave Desert. Much of what is published was produced by two authors: Dr. Matthew L. Brooks of the USGS Western Ecological Research Center, Las Vegas Field Station or Dr. Richard A. Minnich, Department of Earth Sciences, University of California – Riverside. Fortunately, these two researchers have recently collaborated to provide a synthesis of fire ecology of the California Desert Bioregion, including the Mojave Desert, for a new book on Fire Ecology of California (Figure D2).

Figure D2. Book excerpt of California Desert BioRegion (Brooks and Minnich in press).

DESCRIPTION OF DESERT BIOREGION

Physical Geography

The desert bioregion is within the basin and range geomorphic province of western North America, and comprises 27% (110,283 km^2 or 27,251,610 acres) of the total area within California (Miles and Goudy 1997). This large area includes two ecoregional provinces comprised of five ecological sections: The American Semi-Desert and Desert Province (hot-desert province) includes the Mojave Desert, Sonoran Desert, and Colorado Desert sections in the southern 83% of the desert bioregion. The Intermountain Semi-Desert Province (cold desert province) includes the Mono and Southeastern Great Basin sections in the northern 17% of the desert bioregion.

The geomorphology of the desert bioregion is characterized by isolated mountain ranges with steep slopes separated by broad basins containing alluvial fans, lava flows, dunes, and playas. Elevation ranges from 85m below sea level in Death Valley, to 4,328 m above sea level in the White Mountains. Soil taxa range widely from hyperthermic or thermic, aridic Aridisols and Entisols in the Colorado, Sonoran, and Mojave Desert sections, to thermic, mesic, frigid, or cryic, aridic, xeric, or aquic Alfisols, Aridisols, Entisols, Inceptisols, Mollisols, and Vertisols in the Mono and Southeastern Great Basin sections (Miles and Goudy 1997). This wide range in geomorphology and soil conditions translates into a wide range of vegetation and fuel types within the desert bioregion. These vegetation types range from arid shrublands, to semi-arid shrublands, grasslands, and woodlands, to mesic shrublands, grasslands, woodlands, forests.

Climatic Patterns

Although frontal cyclones of the jet stream pass through the region during winter (November and April), virtually the entire desert bioregion is arid due to rain shadows of the Sierra Nevada, Transverse, and Peninsular ranges. Precipitation locally increases with orographic lift in desert ranges, especially those that rise above 2,000m. From July to early September, the region experiences 10-25 days of afternoon thunderstorms from the

North American monsoon originating in the Gulf of California and Mexico. Thunderstorm cells tend to concentrate over high terrain, especially the eastern escarpments of the Sierra Nevada, Transverse, and Peninsular ranges, near Mountain Pass in the eastern Mojave Desert, and the high basin and range terrain between the White Mountains and Death Valley. The mean annual precipitation on valley floors ranges from 10-20 cm in the Mojave Desert and southeastern Great Basin, to 7-10 cm in the Colorado and Sonoran deserts. The annual rainfall total at Death Valley (5.8 cm) is the lowest in North America. Amounts increase to 20-30 cm in the mountains above 2,000 m (x ft), 40 cm in the White Mountains, and 60 cm in the upper leeward catchments of the Sierra Nevada, transverse, and peninsular ranges. The percentage of annual precipitation falling during summer ranges from approximately 20% in the southeastern Great Basin to 40% at the Colorado River in the Sonoran Desert.

Interannual variation in rainfall is relatively high, resulting in highly variable frequency and extent of fires among years. High rainfall produces fine fuels that promote fire spread throughout the desert bioregion, whereas low rainfall reduces live fuel moisture and promotes fire spread in the cold desert sections. Multi-decadal variation in rainfall has also been significant, with periods of relatively high rainfall from the turn of the century until 1 946, a mid-century drought from 1947-1976, and a period of high rainfall 1977-1998 (Hereford et al. in review). This approximately 30-year cycle, coupled with below-average rainfall since 1999, suggest that we may be entering another 30-year drought period, which would likely reduce the frequency and size of fires in the desert bioregion.

The entire desert bioregion has a large annual range of temperature due to its isolation from the maritime influences of the Pacific. There is also large regional variability due to variable elevational relief. Mean January temperatures on valley floors range from -3 to 0° C in the northeastern Great Basin to 7-10° C in the Mojave Desert, and 11-13° C in the Sonoran and Colorado deserts. Because of the importance of valley ground inversions under low insolation, temperatures decrease slowly with altitude to about 0° C at 2,000 m and -8° C at 3,000 m. In summer mean temperatures vary near the dry adiabatic lapse rate due to intense atmospheric heating in the absence of evapotranspiration under high sun. July mean temperatures on valley floors range from 18-20°C in the northeastern Great Basin to 25-30°C in the Mojave Desert and 30-35°C in the Sonoran and Colorado deserts. Maximum temperatures average > 40°C below 1,000 m elevation and occasionally reach 50°C in Death Valley, the Colorado River, and the Salton Sea trough. In the desert mountains, mean temperatures decrease to 20°C at 2,000 m and l0°C at 3,000 m. The decrease in temperature with altitude results in rapid decrease in evapotranspiration which in phase with increasing precipitation results in corresponding increase in woody biomass of ecosystems. Light snowpacks, seldom > 10-15 cm depth, develop in winter, mostly above 2,000 m, although deep snow of 100 cm will persist into spring in subalpine forests > 3,000 m.

Relative humidity during the afternoon in the summer fire season, when fires are most likely to spread, is very low throughout the desert bioregion. Mean July relative humidity ranges from 20-30% in the northeastern Mojave Deserts to 10-20% in the Mojave, Sonoran, and Colorado deserts. Values are low because moisture of the Pacific Coast marine layer is mixed aloft with dry subsiding air masses upon dissipation of the marine inversion, as well as from high temperatures produced by convective heating of surface air layers. The lowest humidity of the year (frequently < 10%) typically occurs in late June, just before the arrival of the North American monsoon.

Lightning frequency is higher in the desert than in any other California bioregion (van Wagtendonk and Cave, 2004). Lightning strikes/year/I00km averaged 27 (sd = 16) from 1985 through 2000, ranging from 32 in the Mono to 12 in the Colorado Desert sections. The bioregions with the next most frequent lightning strikes were the Northeast Plateau (22 strikes/year/100km^2) and Sierra Nevada (20 strikes/year/100km^2).
Most lightning in the desert bioregion occurred from July through September (78%), the result of summer monsoons which develop in the Colorado, Sonoran, and eastern Mojave deserts, and from summer storms that develop in the Sierra Nevada mountains and drift into the southeastern Great Basin and Mono sections. Lightning also occurred primarily during daylight hours, with 81% between 0600 and 1800.

ECOLOGICAL ZONES

From a fire ecology perspective, much of the variation in the desert bioregion relates to patterns of fuel characteristics and fire regimes. Vegetation (fuels), topography, and lightning strikes per unit area vary locally with elevation, and elevational vegetation gradients are correlated positively with latitudinal gradients and ecotones grading into more mesic regions in the immediate rain shadow of the Sierra Nevada, Transverse, and Peninsular ranges. Accordingly, we consider elevation as a primary determinant of fire ecology zones in the desert bioregion. The ecological zones described below are listed in order of increasing elevation, except for the riparian zone, which transcends many of the other zones.

Low elevation desert shrubland zone. This is the predominant ecological zone in the Sonoran Desert section. Major vegetation types include alkali sink vegetation and the lower elevations of creosote bush scrub (Munz and Keck 1959) and succulent scrub (Rowlands 1980). Surface fuel loads and continuity are typically low, hindering the spread of fire.

Middle elevation desert shrubland and grassland zone. This is the predominant ecological zone in the Mojave Desert, Colorado Desert, and Southeastern Great Basin sections, where it typically occurs as an elevational band above the low elevation zone and below the high elevation zone. It also occurs at the regional ecotone between the Mojave and Great Basin deserts. Major vegetation types include Joshua tree woodland, shadscale scrub, the upper elevations of creosote bush scrub (Munz and Keck 1959), blackbrush scrub, and desert scrub-steppe (Rowlands 1980). Surface fuel characteristics are variable, but loads and continuity can be relatively high, facilitating the spread of fire.

High elevation desert shrubland and woodland zone. This is the predominant ecological zone in the Mono section. It also occurs at the tops of most Mojave Desert mountains, or just below desert montane forests where they occur, and along the margins of the Sierra Nevada, Transverse, and Peninsular mountain ranges where they intergrade with yellow pine forests. Major vegetation types include sagebrush scrub, pinyon-juniper woodland, and desert chaparral (Munz and Keck 1959). Surface fuel loads and continuity are high where sagebrush scrub and chaparral dominate, facilitating the spread of fire. However, surface fuels are replaced by very high loads of crown fuels in closed pinyon-juniper woodlands, where fires only occur under extreme fire weather conditions and are typically very intense.

Desert montane woodland and forest zone. This zone is very limited in total area, and occurs almost exclusively in the Mono and Southeast Great Basin sections. Major vegetation types include bristlecone pine forest and alpine fell-fields (Munz and Keck 1959). Surface fuels are typically sparse, separating patches of crown fuels and hindering the spread of fire.

Desert riparian woodland and oasis zone. This zone includes a diverse set of vegetation types that do not fit into any single elevational range. Vegetation types include oases and riparian woodlands, shrublands, grasslands, and marshes. Surface fuels loads and continuity can be very high, facilitating fire spread, although vertical continuity of ladder fuels and horizontal continuity of crown fuels are often insufficient to carry crown fires.

OVERVIEW OF HISTORIC FIRE OCCURRENCE

The primary factor controlling fire occurrence in the desert bioregion is fuel condition, specifically fuel continuity and fuel type. Where fuel continuity is low, such as in most of the low elevation and desert montane ecological zones, fires will not typically spread beyond ignition points, whether the cause is anthropogenic or natural. Even where continuity is relatively high, it may be comprised primarily of fuel types that do not readily burn except under the most extreme fire weather conditions. The coarse, woody fuels of pinyon juniper woodlands in the high elevation ecological zone are a good example. Thus, variations in fuel condition are central to any attempts to evaluate past or current patterns of fire occurrence.

Pre-historic Period

Pre-historic fire regimes during the Holocene have not been quantitatively described for most of the southwestern desert regions, largely because the usual tools for reconstructing fire histories, such as analyzing trees for fire scars or coring sediments in swamps or lakes for charcoal deposits, cannot be used where the required trees or lakes are not present. As a result, past fire regimes must be inferred based on current observations and data.

Packrat midden fossil data suggest that most of the desert bioregion has been under arid to semi-arid conditions since the beginning of the Holocene, with pinyon and juniper woodlands on hill slopes and at higher elevations, and low scrub and perennial grasslands in basins (van Devender and Spaulding 1979}. Most interior basins in the desert bioregion did not support permanent lakes except those receiving runoff from the Sierra Nevada, transverse, or peninsular ranges. Thus, the major vegetation types that presently occur in the desert bioregion, and the ecological zones described in this chapter, were likely present in the desert bioregion throughout the Holocene, expanding and contracting relative to each other as they shifted up and down the elevational gradients with periods of low and high rainfall.

The low elevation ecological zone probably contained low and discontinuous fuels, hindering fire spread and resulting in low intensity, patchy burns and long fire return intervals. Consecutive years of high rainfall would have increased fine fuel loads and continuity, and may have allowed fire to spread periodically in this ecological zone, especially were rainfall was highest along the western margins of the Mojave and Colorado deserts close to the Transverse and Peninsular mountain ranges.

The middle elevation, high elevation, and riparian zones likely had sufficient perennial plant cover to periodically carry fire in the pre-historic past without significant amounts of fine fuels. Because these fires would have been carried by relatively high cover of perennial shrubs and grasses, they were likely moderate intensity, stand replacing fires, as they typically are today.

Fuels in the desert montane zone were probably discontinuous resulting in small, patchy, and very infrequent surface or passive crown fires. Evidence of this is the presence of the long-lived (>3,000 years}, but fire sensitive, bristlecone pine trees. It seems highly probable that fuel conditions and fire regimes have changed little since the early Holocene across most of the desert bioregion, although there is no direct evidence supporting this conclusion. It is also likely that fuel conditions and fire regimes in localized areas, especially in the middle elevation zone, have changed from prehistoric conditions since the late 1800s due to land use activities and invasions by non-native annual grasses. We discuss these changes in more detail below.

Historic Period

It is possible that livestock grazing beginning in the 1880s reduced perennial plant cover, especially cover of perennial grasses, and further reduced landscape flammability in the desert bioregion. However, as fuels were potentially reduced due to grazing, ignitions probably increased as fire came into use by livestock operators to convert shrub lands into grasslands and increase forage production, especially in the Mono and middle to high elevations of the Southern Great Basin and Mojave sections. For example, rangelands in southern Nevada, southwestern Utah, and northwestern Arizona were extensively burned during the early 1900s to promote the growth of perennial grasses (Brooks et al. 2003).

Similar rangeland burns may have also occurred in the southern and eastern Mojave Desert and the far western Colorado Desert, where summer rainfall occurs in sufficient amounts to support large stands of perennial grasses. However, most of the southern hot desert regions are too dry to support sufficient native fuels to carry fire, so even if ranchers tried to burn, they may have often been unsuccessful.

Analyses of historical aerial photos from 1942,1953-54,1968,1971-74,1998, and 1999 at Joshua Tree National Park indicate that there were periodic fires there prior to 1942 (Minnich, 2003), during a 30-year period of relatively high rainfall that lasted until 1946 (Hereford et al. in review), but most were <300 acres and the largest was 1,500 acres, and all occurred in the middle and high elevation ecological zones (Minnich, 2003).
The spatial clustering of burns in some areas suggest that deliberate burning was practiced, possible to improve range production for livestock. During the mid-century drought, only three small fires occurred, all during the 1960s and Joshua tree woodlands of the middle elevation ecological zone. Soon after the drought ended in 1977, fires again became more prevalent, but their size and numbers eclipsed what was observed prior to the mid-century drought. The first was a 6,000 acre fire in 1978, and the most recent was a 15,000 acre complex of fires that burned over a period of 5 days in 1999, both in the middle and high elevation ecological zones. These recent fires at Joshua Tree National Park were fueled largely by old stands of native trees, shrubs, and perennial grasses, but fire spread was additionally facilitated by stands of the non-native annual grasses red brome (*Bromus madritensis* ssp. *rubens*) and cheatgrass (*Bromus tectorum*), especially where the fire passed through areas previously burned since 1978 (National Park Service, DI-1202 fire reports).

Current Period

Records from land management agencies provide information on recent fires that can be used to reconstruct current fire regimes across the desert bioregion. We extracted data from fire occurrence records (D1-1202 reports) archived by the United States Department of the Interior and Department of Agriculture between 1980 and 2001 to create some basic summaries for each of the five ecological sections in the California desert. Although this 21-year database is too short to capture the full range of potential burning conditions, such as being coincident with a period of above-average rainfall from 1977 - 1998 (Hereford et al. in review), it represents the best data available to approximate fire regimes since 1980 in the desert bioregion of California.

The primary message from these data is that the proportion of total area that burned per year from 1980 to 2001 is very small, peaking in the Mono section at 0.3%/yr (292 ha/1,000 mlyr), resulting in potential fire cycle of 342 years in the Mono section.

The annual fire frequency and area burned were highest in the Mono section, and lowest in the southern Great Basin section, peaking from May through September. Among the hot desert regions, fire frequency was highest in the Mojave and Colorado deserts, and the annual area burned was highest in the Colorado Desert. The percentage of lightning strikes that resulted in fire was highest in the Mono and Colorado Desert sections, probably due to high fuel continuity caused by the prevalence of sagebrush steppe in the Mono section, and red brome dominated creosote bush scrub in the western Colorado section. The Colorado Desert section had the highest ratio of human:lightning caused fires. This is probably due to both the high human population density and agricultural activity in the Coachella and Imperial valleys, and the low occurrence of lightning in the Colorado Desert. The northern cold desert region had the lowest frequency of fires caused by humans, probably due to its remoteness from major human population centers.

In a separate analysis of agency fire data from 1980 to 1995 in the Mojave, Colorado, and Sonoran desert sections, fires were found to be clustered in regional hotspots (Brooks and Esque 2002), where they were much more frequent and burned more proportional area than the desert-wide averages indicated. Annual fire frequency increased significantly 1980 through 1995 (i = 0.27) (Brooks and Esque, 2002), but the increase was only significant in the low and middle elevation zones below 4,200 ft (~ = 0.32, 1980-2001) (Matchett et al. in preparation). This increase was due to increased number of fires caused by humans, since the number of lightning-caused fires remained constant (Brooks and Esque, 2002). Another possible contributor to increased fire frequency was a general increase in fine fuel loads caused by increased dominance by non-native annual grasses beginning in the late 1970s (e.g. Hunter 1991) and continuing on through the 1990s (M. Brooks personal observation), probably the result of above-average rainfall from 1976-1998 (Hereford et al. in review).Although most fires were small and started along roadsides, most of the large fires occurred in remote areas far from major roads, and were typically started by lightning (Brooks and Esque, 2002).

MAJOR ECOLOGICAL ZONES

In this section we describe the basic fire ecology of the predominant plant species in each ecological zone. We also discuss patterns of postfire succession, and interactions between plant communities, fire behavior, and fire regimes. More details on the fire ecology of a wider range of desert species can be found in other recent publications (Brown and Smith 2000, Esque and Schwalbe 2002).

Low Elevation Desert Shrubland Zone

This zone includes two primary vegetation types. Alkali sink vegetation occurs on poorly drained saline and/or alkaline playas, flats, and fans approximately -80 to 1,200m throughout all the ecological sections. Plant communities include iodine bush-alkali scrub, a1lscale-alkali scrub, Mojave saltbush-allscale scrub, and saltgrass meadow (Rowlands 1980). Creosote bush scrub vegetation occurs 0 to 1,200 m on well-drained flats, fans, and upland slopes of the Mojave, Colorado, and Sonoran Desert ecological sections. However, only the lower elevations below about 900 m were perennial plant cover is relatively low are typical of the low elevation desert shrubland zone. Plant communities include creosote bush scrub, cheesebush scrub, succulent scrub (Rowlands 1980).

Fire responses of important species

Most shrubs in the low elevation zone do not survive after being completely consumed by fire (Humphrey 1974, Wright and Bailey 1982) but since many fires in this zone are patchy and low intensity, plants frequently survive in unburned islands. Low fire temperatures in interspaces, and high temperatures beneath woody shrubs, results in relatively higher seedbank mortality for annual plants that frequent beneath-shrub than interspace microhabitats (Brooks 2002). A few perennial species evolved to resprout after natural flooding disturbances typically resprout after being burnt, such as desert willow (*Chiloposis linearis*), catclaw (*Acacia greggi*) smoke tree (*Dalea spinosa*), and cheesebush (*Hymenoclea salsola*). Cheesebush can have almost 100% survival rates even after being totally consumed by fire. Cacti are usually only scorched during fires, as flames propagate through their spines, but the stems do not ignite due to their high moisture content. Individuals with high levels of scorching typically die from uncontrolled desiccation. Cactus regeneration can occur from resprouting of partially scorched plants, or rooting of fallen unburned stem fragments, but less frequently from establishment of new seedlings.

The most frequently encountered and dominant shrub in this zone, creosotebush (Larrea tridentata), can have 25-80% survival rates 8 years postfire when it is only scorched (1-10% biomass loss), and 0-12% survival rates by year 8 when it is consumed by fire (11-100% biomass loss) (Table 4). The wide range in survival rates among creosote bushes is primarily due to their variable physiognomy and variable fuel loads beneath their canopies, which translates into variable fire intensity and vertical continuity from surface to canopy fuels. Individuals with hemispherical canopies that extend to the ground, and have high beneath-canopy fuel loads from accumulated dead branches and senesced annual plants, are most likely to be totally consumed by fire. In contrast, individuals with canopies in the shape of inverted cones that do not extend to the ground, and have low beneath-canopy fuel loads, are least likely to be consumed by fire.

Fire regime-p/ant community interactions

This is the zone that Humphrey (1974) was primarily referring to when he stated that in the Mojave Desert ". ..fires are a rarity, and the few fires that do occur cause little apparent damage to the various aspects of the ecosystem. .." This is largely because fuels are discontinuous and characterized by a sparse 8 to 15% cover of woody shrubs, and the large interspaces between shrubs are mostly devoid of vegetation, inhibiting fire spread. A recent summary of fire regimes of the United States (Schmidt et al. 2002) assumed that Kuchler's barren vegetation type (Kuchler, 1964), which covers most of the low elevation desert shrub land zone, is mostly devoid of vegetation and therefore fireproof. However, 9% of fires and 7% of the total area burned between 1980 and 2001 occurred within the barren vegetation type in the California desert bioregion. Thus, fires do occur in the low elevation desert shrubland zone, albeit not as frequently and over less area than in the other zones of the desert bioregion.

Fire behavior and fire regimes in this zone are affected primarily by the ephemeral production of fine fuels from annual plants. Years of high winter and spring rainfall can increase continuity of fine fuels by stimulating the growth of annual plants that fill interspaces and allow fire to spread (Brown and Minnich 1986, Schmid and Rogers 1988, Rogers and Vint 1987, Brooks 1999). Native annuals that produce some of the most persistent fuelbeds include the annual grasses six-weeks fescue (*Vupia octoflora*) and small fesue (*Vupia microstachys*), and the large forbs fiddleneck (*Amsinckia tessellata*), tansy mustard (*Descurania pinnata*), and lacy phacelia (*Phacelia tanacetifolia*), compared to a whole suite of smaller native forbs (119 species, Brooks 1999). Infrequently, successive years of high rainfall may have allowed these native species to build up fine fuel loads in interspaces sufficient to carry fire. Low elevation fires carried by high loads of native annuals typically only burn dead annual plants and finely-textured sub-shrubs, leaving many of the larger woody shrubs such as creosotebush unburned. Thus, the historic fire regime was likely characterized by relatively small, patchy, low intensity surface fires, and a truncated long fire return interval.

The invasion of non-native annual grasses into the desert bioregion introduced new fuel conditions. Species such as red brome and Mediterranean grass (*Schismus arabicus* and *S. barbatus*) provide more lasting and less patchy fine fuelbeds than do native annual plants, breaking down more slowly and persisting longer into the summer and subsequent years (Brooks 1999). These new fuel conditions have the potential to increase the size, decrease the complexity, and shorten the time interval between desert fires, although fire intensity will likely decrease because fine herbaceous non-native fuels are replacing coarse woody native fuels. These fire regime changes have occurred over a small fraction of the low elevation ecological zone, and fire regimes over the vast majority of this zone are within the historical range of variation.

Mediterranean grass is the most widespread and abundant non-native annual grass in the low elevation shrubland zone, although red brome may predominate under large shrubs or in the less arid parts of this ecological zone. It has fueled fires as large as 41 ha (BLM DI-1202 records) and interspace fuel loads of as little as 112kg/ha can carry fire (Brooks 1999). Because these fires burn with low intensity, soil heating is negligible and most woody shrubs are left unburned.

The recent spread of Sahara mustard (*Brassica tournefortii*) throughout the low elevation shrublands in the California deserts has caused concern that this invasive mustard may introduce a significant new fuel type to the region. During years of high rainfall this invasive annual can exceed 1m in height with a rosette of basal leaves 1m across, and even moderately sized plants can produce as many as 16,000 seeds (M. Brooks unpublished data). Plants can remain rooted and upright through the summer fire season, and when they finally do break off they blow like a tumbleweed and lodge in shrubs or fencerows, accumulating piles of fuels similar to Russian thistle (*Salsola* spp.). There are no records of fires caused by Sahara mustard in the California desert, however, the combination of this species with red brome in the understory helped fuel a 50 acre fire in creosotebush scrub in northwest Arizona (M. Brooks, personal observation). During the 5 years after this fire, Sahara mustard and red brome have come to dominate the site while the native creosote bush (*Larrea tridentata*) has yet to show signs of recovery.

Non-native annual plants that evolved in other desert regions will likely be most successful at persisting in the California desert bioregion. For example, Mediterranean grass and Sahara mustard respectively evolved in the arid Middle East and Northern Africa, and they have also successfully established in the desert bioregion (Brooks 2000a, Minnich and Sanders 2000). At three sites in the western Colorado Desert, these non-native species successfully persisted through two major droughts, which occurred during the end of the 1980s and 1990s (Hereford et al. in review). Their cover values in 1983, 1988, and 1990 through 2001 were comparable or higher than those of the non-native forb red-stemmed filaree (*Erodium cicutarium*), which is a poorer fuel source for fires (Brooks 1999), and all native forbs combined.

Middle Elevation Desert Shrubland and Grassland Zone

This zone includes five primary vegetation types. The upper elevations of creosotebush scrub generally occur at 900 to 1,200m and contain higher perennial plant cover than the lower elevations of this vegetation type. Joshua tree woodland occurs on well-drained loamy, sandy, or fine gravelly soils of mesas and gentle slopes from 760 to 1,300m in the Mojave Desert and Southeastern Great Basin sections. Shadscale scrub occurs on heavy, rocky, often calcareous soils with underlying hardpan from 1,000 to 1,800m in the Mono, Southeastern Great Basin, and Mojave Desert sections. Blackbrush occurs on well drained, sandy to gravelly often calcareous soils from 1,000 to 2,000m in the Southeastern Great Basin and Mojave Desert sections. Desert scrub-steppe vegetation types are intermixed with a wide range of other plant communities from the low to the high elevation ecological zones, but they are most common in the middle elevation zone. Indian ricegrass scrub-steppe and desert needlegrass scrub-steppe typically occur were winter rainfall predominates within creosote bush scrub (Rowlands 1980). Big galleta scrub-steppe typically occurs in creosote bush scrub below 1,000 m, and in Joshua tree woodland and blackbrush scrub above 1,000 m.

<u>Fire responses of important species</u>

Higher fuel loads and more continuous fuelbeds in the middle elevation ecological zone result in higher intensity fires and higher frequency of top- killing in plants than in the low elevation zone. However, more species in this zone are likely to resprout after being top-killed. Perennial grasses such as desert needle grass (*Achnatherum speciosa*), galleta grass (*Pleuraphis rigida* and *P. jamesii*), and Indian ricegrass (*Achnatherum hymenoides*) readily resprout after burning. Spiny menodora (*Menodora spinescens*) and joint-fir (*Ephedra* spp.) often survive fire because their foliage does not burn readily. In contrast, some shrub species such as blackbrush (*Coloegyne ramosissima*) and winterfat (*Kraschennikovia lanata*) rarely survive burning.

Blackbrush (*Coleogyne ramosissima*) is one of the more flammable native shrubs in the desert bioregion, due to its high proportion of fine fuels and optimal packing ratio. In the rare case that only a portion of a shrub is consumed, it may survive and resprout from the root crown. This resprouting was observed within the first few postfire years (Bates 1984), and these resprouts were still evident 20 years later (M. Brooks personal observation), at a site in the Mono section near Bishop, California. It is commonly thought that blackbrush stands take centuries to recover (Bowns 1973, Webb et al. 1988). However, analyses of historical photographs from Joshua Tree National Park and southern Nevada indicate that blackbrush stands can recover within 50- 75 years (M. Brooks unpublished data, Minnich 2003), although other historical photographs do not indicate recovery within this time interval (M. Brooks, unpublished data).

Yucca species such as Joshua tree (*Yucca brevifolia*), Mojave yucca (*Yucca schidigera*), banana yucca (*Yucca baccata*), and our Lord's candle (*Yucca whipplei*) are typically scorched as fire propagates through the shag of dead leaves that line their trunks. The relatively small size and more optimal packing ratio of dead Joshua tree leaves compared to dead Mojave or banana yucca leaves, increases the frequency at which they are completely burned. This may partly explain why Joshua trees are more frequently killed by fire. All four yucca species readily resprout after fire, but Joshua tree resprouts are often eaten by herbivores or otherwise die soon after burning. Postfire recruitment of new Joshua trees is infrequent, and likely occurs during years of high rainfall. No seedlings or saplings were observed in burns <10 years old, and <10 individuals/hectare were present on burns >40 years old in Joshua Tree National Park (Minnich 2003). Joshua tree populations along the extreme western edge of the desert bioregion often resprout and survive more readily after fire than those further east (M. Brooks personal observation). The cycle of relatively frequent fire and resprouting results in short, dense clusters of Joshua tree clones near Walker Pass and the western end of the Antelope Valley, in Cajon Pass, and in pinyon-juniper woodlands of the Transverse ranges. High resprouting rates may have evolved in local ecotypes which became adapted to relatively high fire frequencies at the ecotone between the desert bioregions and more mesic ecosystems to the west.

Fire regime-plant community interactions

Some of the most continuous native upland fuels in the desert bioregion occur at the upper elevations of this zone, especially in areas dominated by blackbrush. Invasive annual grasses have contributed to increased fire frequency since the 1970's (Brooks and Esque, 2002), although the native perennial vegetation in this zone can at times be sufficient to carry fire during extreme fire weather conditions (Humphrey 1974). Between 1980 and 2001, 49% of all fires and 45% of total area burned occurred in Kuchler's desert shrubland vegetation type, which is roughly analogous to the middle elevation ecological zone.

At the lower elevations within this zone, where creosotebush is co-dominant with a wide range of other shrubs and perennial grasses, fire spread is largely dependent on high production of fine fuels filling interspaces during years of high rainfall (Brown and Minnich 1986, Schmid and Rogers 1988, Rogers and Vint 1987, Brooks 1999). At higher elevations within this zone, where blackbrush is often the primary dominant plant, fire spread is not so dependent on the infilling of shrub interspaces during years of high rainfall and fire occurrence does not vary as much inter-annually compared to lower elevations. Thus, the historic fire regime was likely characterized by relatively moderate to large sized, patchy to complete, moderate intensity, surface to crown fires, and a long fire return interval.

The post-fire response of plant communities in blackbrush scrub is illustrative of the general responses of other desert scrub communities in the middle and high elevation ecological zones. Blackbrush fires remove cover of woody shrubs which is soon replaced by equivalent cover of herbaceous perennials and annual plants (Brooks and Matchett 2003). Alien species such as red brome, cheatgrass (*Bromus tectorum*), and red-stemmed filaree typically increase in cover after fire, but only if rainfall is sufficient to support their growth and reproduction. Recovery of blackbrush stands may occur within 50 years (Minnich 2003, M. Brooks, unpublished data), but perhaps more typically take over 100 years (Webb et. 1988, Bowns 1973).

Red brome is the dominant invasive grass at middle elevations in the California desert bioregion. This invasive grass produces higher fuel loads and fuel depths than does Mediterranean grass, and accordingly carries fire into the crowns of large woody shrubs more readily, producing more intense fires (Brooks 1999). Cover of red brome can become greater and more continuous after fire, promoting recurrent fire. This positive invasive plant-fire regime cycle (sensu Brooks et al. in review) has shifted fire regimes outside of their historical range of variation in some regional hotspots (Brooks and Esque 2002), although fire regimes in most of the middle elevation zone are similar to historical conditions.

The recent invasion of the non-native annual grass African needlegrass (*Stipa capensis*) into the western ecotone of the Colorado Desert with the Peninsular ranges the 1990s has helped fuel at least one 600 acre fire (R. Minnich, personal observation). There are early indications that this species can survive relatively dry years, suggesting that it may spread and become another source of fine fuels that may further alter fire regimes in the desert bioregion.

High Elevation Desert Shrubland and Woodland Zone

This zone includes three primary vegetation types. Sagebrush scrub occurs in 1,100 to 2,800 m, although it can extend to 3,800 m in the White Mountains. Pinyon-juniper woodland occurs 1,300 to 2,400 m, and can reach 2,700 m in the White Mountains. Both vegetation types occur in the Mono, Southeastern Great Basin, and Mojave sections. Among the pinyon-juniper vegetation types, the Utah juniper – singleleaf pinyon association is the most widespread, occurring in the Mono, Southeastern Great Basin, and eastern Mojave Desert ecological sections of California. The California juniper- single-leaf pinyon association occur along the desert slopes of the transverse ranges at the edge of the Mojave Desert Section, with California juniper dominating below 1,700 m and single-leaf pinyon dominating above. The California juniper -four-needle pinyon association occurs in small populations along the ecotone with the South Coast Bioregion in the peninsular ranges at the edge of the Colorado Desert section. Desert chaparral is the least prevalent of the major vegetation types in this ecological zone. It occurs on the middle slopes of the transverse ranges adjacent to the Mojave Desert, and the peninsular ranges adjacent to the Colorado Desert, below the mixed conifer forests, and in the same general elevation range as sagebrush scrub and pinyon-juniper woodland.

Fire responses of important species

Relatively high fuel loads result in high fire intensity, but the mortality rates can vary widely among species. Big sagebrush (*Artemisia tridentata*) and rubber rabbitbrush (*Chrysothamnus nauseosus*) are typically killed by fire, but they often re-establish readily from wind-dispersed seeds. Cliffrose (*Purshia mexicana*) is typically killed by fire, whereas its close relative, antelope bitterbrush (*Purshia tridentata*), exhibits highly variable responses to fire, often resprouting. Interior chaparral species (*Quercus cornelius-mulleri*, *Q. turbinella*, *Cercocarpus betuloides*, *Arctostaphylos glauca*, *A. glandulosa*, *Nolina* spp.) either resprout or reseed soon after fire, but lower rainfall and sparser vegetation cover results in less frequent fire and slower recovery rates than is typical of cis-montane chaparral.

Pinyon pine (*Pinus monophylla*, *P. edulis*) and juniper (*Juniperus osteosperma*, *J californica*) are typically killed by fire, but the 100+ years it takes for fuels to build up to levels that could carry fire allow enough time for trees to re-establish in most cases. Juniper typically re-establishes from seed sooner than pinyon pine. Initial establishment of single-leaf pinyon pine appears to be delayed 20-30 years by sun scald and/or freeze/thaw soil heaving until the establishment of the shrub layer and young juniper trees which act as nurse plants (Wangler and Minnich 1996). The first pinyon recruits establish within shrub canopies, often near root axes. The growth of pinyon pine canopy eventually reduces freeze-thaw processes after 75 yr, setting off a chain-reaction of spatially random recruitment throughout burns. Pinyons develop canopy closure after 100-150 yr which is accompanied by a decline in the surface vegetation, due apparently to shrub senescence and shade stress.

Fire regime-plant community interactions

Fuel continuity is similar to that of the middle elevation zone, but the fuels are generally more woody and difficult to ignite. In addition to high plant cover, the prevalence of steep slopes in this ecological zone facilitates the spread of fire. Due to the high biomass of woody fuels created by juniper and pinyon pine, and to a lesser extent sagebrush (*Artemisia* spp.), bitterbrush, cliffrose, and scrub oak (*Quercus turbinella*), the fires that do start are among the most intense encountered in the desert bioregion. Between 1980 and 2001, 33% of fires and 45% of the total area burned occurred in Kuchler's sagebrush, juniper-pinyon, and chaparral vegetation types which are characteristic of the high elevation ecological zone.

Fire spread can occur most any year in sagebrush steppe, although it is more likely when live fuel moisture is low during periods of drought, when fine fuel loads (especially cheatgrass) are high following years of high rainfall, or during periods of high winds and low relatively humidity. Fires are patchy to complete, moderate intensity passive crown to crown fires, depending the continuity of the woody shrub fuels. Fire spread in pinyon juniper woodlands is most probable when live fuel moisture and relative humidity are low and winds are high. When fires did historically occur, they were mostly large, intense crown fires, burning through woodland crown fuels. At the interface between the two vegetation types, a surface to passive crown fire regime is the norm, as fire spreads through woody and herbaceous surface fuels and occasionally torches woodland fuels, especially younger trees. The historic fire regime was likely characterized by relatively large, patchy to complete, moderate intensity surface to crown fires, and a long fire return interval. Sagebrush stands generally require 30-100 years to recover following fire (Whisenant 1990). Where cheatgrass has dramatically shortened fire return-intervals, especially in the lower elevation Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyominenesis*) communities, sagebrush steppe has been converted to non-native annual grassland. At the higher elevation mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*) communities, this type conversion is much less common, since the native shrubs and perennial grasses recover much more rapidly after fire.

Fire suppression coupled with removal of fine fuels by livestock grazing has allowed pinyon juniper woodlands to encroach on sagebrush steppe across much of the western United States (Miller and Tausch 2001). This pattern may be occurring in the Mono section of the desert bioregion where rainfall is relatively high, but it is less likely that woodland encroachment has occurred in the more arid regions to the south in the desert bioregion, due to low primary productivity rates, as recent resampling of 1929-34 VTM survey plots reveal no significant changes in forest density (R. Minnich, unpublished data). Pinyon juniper woodlands adjacent to the Transverse mountain ranges have experienced long periods between stand-replacement fires both before and after fire suppression began (fire rotation periods, 450 years; Wangler and Minnich 1996).

Fires in pinyon juniper woodlands are least frequent in open stands at lower elevations and more frequent in dense forests at highest elevations, in response to changing productivity and fuel accumulation gradients with increasing annual precipitation toward higher elevations. The upper elevation ecotones between pinyon-juniper woodlands and mixed conifer forest are typically very narrow, due to truncated disturbance gradients related to fire behavior and stem mortality. The thin bark of pinyon pine prevents their survival in the frequent surface fire regime typical of mixed conifer forests. Alternatively, postfire surface fuels appear to lack sufficient biomass to support short-period bums, and as canopy closure occurs in pinyon and juniper woodlands, surface fuel loads and continuity are further reduced. Thus, a historical discontinuity in fire return intervals probably existed along the ecotones between mixed conifer forests and pinyon woodlands in which predominantly understory fires at high elevations shift to long-period stand-replacement burns at lower elevations in response to differences in stand structure, fire behavior, and tree survivorship.

Desert Montane Woodland and Forest Zone

There are two primary vegetation types in this ecological zone. Bristlecone-limber pine forests (*Pinus longaeva*, *Pinus flexilis*) occur on well-drained, shallow, dolomitic soils from 2,600 to 3,800 m in the Inyo, White, Panamint, Funeral, and Grapevine mountains. Alpine fell-fields occur above timberline, primarily in the White Mountains. Small white fir (*Abies concolor*) forest enclaves also occur on north-facing slopes from 1,900 to 2,400m in the New York, Clark, and Kingston mountains of the Mojave Desert section (Rowlands 1980).

<u>Fire responses of important species</u>

The flagship tree species of this ecological zone, bristlecone pine (*Pinus longaeva*) and limber pine (*Pinus flexilis*), have thin bark which makes them susceptible to mortality during fires. Although most individuals are struck by lightning by the time they are 1,000 years old, strikes may not result in the entire tree burning, since many old individuals have scars resulting from multiple lighting strikes. The presence of ancient bristlecone pine individuals is testimony to the historical infrequency of fire. As a result, most plant species in this zone are not adapted to recovery from fire, although species associated with other periodic natural disturbances such as from colluvial erosion may be able to resprout after burning.

<u>Fire regime-plant community interactions</u>

Fuels are very discontinuous, but in contrast to the low elevation zone, ephemeral production by annuals during yeas of high rainfall adds very little to the fuel bed, due to shallow soils, low temperatures, and a short growing season. As a result, surface fires are extremely rare, and most fires that do occur either spread through the crowns of pines during extreme fire weather conditions, but even these are very small (<l ha). Between 1980 and 2001, <1% of all fires and total area burned occurred in Kuchler's great basin pine, alpine meadows-barren, and mixed conifer vegetation types characteristic of the desert montane ecological zone.

Low productivity results in very low fuel loads and continuity in the desert montane forests. Except on steep, north-facing canyons, heavy fuels are widely spaced, and fine fuels are low and relatively unflammable, making it difficult to carry fire in this landscape. Thus, the historic fire regime is characterized by truncated small, patchy, variable intensity, passive crown fires, and a truncated long fire return interval.

Desert Riparian Woodland and Oasis Zone

Riparian woodlands occur primarily along the Colorado and Mojave river corridors adjacent to low elevation shrub lands in the southern desert region. Other examples can be found in the Amargosa Gorge, Whitewater River, Andreas Canyon, and Palm Canyon. In the northern desert region, riparian woodlands occur along the Owens and Walker rivers and the many creeks along the east slope of the Sierra Nevada Mountains. Oasis woodlands occur in isolated stands such as the Palm Canyon, Thousand Palms, and Twentynine-palms oases in the Colorado Desert section.

Fire responses of important species

Woodland dominants such as Fremont cottonwood (*Populus fremontii*) honey mesquite (*Prosopis glandulosa*), and willows (Salix spp.) typically resprout after being topkilled. However, resprouting individuals and seedlings are susceptible to mortality during recurrent fires. Oasis species such as fan palm (*Washingtonia filifera*) benefit from frequent, low-intensity fire, which reduces competition for water from other plants growing at the surface, and allow new seedlings to become established.

Fire regime-plant community interactions

.Fuel characteristics and fire behavior are extremely variable, due to the wide range of vegetation types that characterize the riparian zone. In general fuels are typically continuous and fuel loads high, but fuel moisture content is also often high. Fires may not carry except under extreme fire weather conditions. Thus, the historic fire regime is characterized by small to moderate sized, complete, high intensity passive to active crown fires, and a short to moderate fire return interval.

In riparian woodlands the invasives saltcedar (*Tamarix* spp), and less frequently giant reed (*Arundo donax*), create ladder fuels that allow fire to spread from surface fuels of willow, saltbush, sedge, reed, and arrow weed (*Pluchea sericea*) into the crowns of overstory Fremont cottonwood trees, top-killing them. After an initial fire, these invasive quickly recover and surpass their pre-fire dominance, promoting increasingly more frequent and intense fires which, can eventually displace most native plants.

In palm oases, Washington fan palms (*Washingtonia filifera*) depend on surface fire to clear understory species such as honey mesquite and saltbush, and create suitable sites for establishment of young palms. However, these sites can be pre-empted by saltcedar as it rapidly recovers after fire. The ladder fuels saltcedar creates can also carry fire into the crown of fan palms, increasing the incidence of crown fires.

MANAGEMENT ISSUES

Fuels Management

The deserts of southwestern North America are one of the fastest growing regions in the United States. As human populations increase, so to do the number of people living at the wildland- urban interface, which complicates fire management in many ways. Increasing human populations can also potentially change fuel characteristics, through increased nitrogen deposition rates that may increase fine fuel loads (Brooks 2003) and the increased chance of new plant introductions that could add new fuel components and fire hazards to the region. Since fire spread is mostly limited by the availability of contiguous fuels, fuel management can be a very important tool for fire managers in the California desert bioregion, even though the areas in which it is used may be a small percentage of the total region, limited to where fuels are sufficient to carry fire.

Herbaceous fuel management

In the desert bioregion, the fuel component of greatest concern is the continuous cover the non-native annual grasses red brome, cheatgrass, and Mediterranean grass that appears during years of high rainfall. Although populations of these non-native annual plants and their resultant fine fuel loadings wax and wane with annual and multi-decadal fluctuations in rainfall, they have changed the rules of the game regarding fire behavior and fire regimes in many parts of the desert bioregion, especially in the low elevation ecological zone where their presence is almost a prerequisite for large fires.

Despite all the concern surrounding the non-native species already dominating the desert bioregion, new grass invaders such as fountain grass (*Pennisetum setaceum*), buffelgrass (*Cenchrus ciliare*), and African needlegrass, and possibly invasive mustards such as Sahara mustard, may pose additional fire hazards in the future. For example, in the Sonoran Desert, buffelgrass invasion coupled with frequent fire has converted desertscrub to non- native grassland in Mexico (Burquez et al. 2002), has created fuels sufficient to carry fire in Arizona, and has recently appeared in southeastern California (M. Brooks personal observation). Land managers who once lamented the damage caused by fires fueled by red brome in southern Arizona are even more concerned now about the potential effects of buffelgrass (S. Rutman, Organ Pipe Cactus National Monument, personal communication). Buffelgrass is currently being considered for addition to the Arizona Department of Agriculture, Noxious Weed List due primarily to its ability to alter fire regimes (E. Northam, personal communication). Thus, fine fuels management should be closely tied to invasive plant management, because the predominant plant invaders in the southern part of the desert bioregions are herbaceous species (Brooks and Esque, 2002). This is important both from the perspective of managing invasive plant fuels that are currently present, and preventing the establishment of new invasive plants that may change fuel structure and potentially cause even greater fire management problems in the future.

Livestock grazing has been mentioned as a possible tool for managing fine fuels in the desert bioregion (Brooks et al. 2003, Minnich 2003). It may reduce fine fuel loads temporarily, and be effective for managing fuels in specific areas such as within the wildland urban interface. However, grazing may also reduce cover of late seral native plants and replace them with non-native annual and other early seral plant species (Brooks et. al in review) that are often more flammable. The effectiveness of livestock grazing is currently being evaluated as a fuels reduction tool for cheatgrass in the Mono section of the desert bioregion (M. Brooks et al., unpublished data).

Woody fuel management

Where native plant cover is sufficient to carry fire without the addition of fine fuels from non-native plants, coarse woody fuels are the major concern of fire managers. In the central and southern parts of the desert bioregion, blackbrush intermixed with perennial grasses, Joshua trees, and juniper produce the right mix of high fuel continuity and fuel loads, fuel packing ratio that facilitate combustion, and fuels with the capability to produce flaming brands, that can cause large intense fires with frequent spotting ahead of the flaming front. Although infrequent, intense, stand-replacing fires are a natural part of blackbrush shrubland ecology, these types of fires are not desirable when they occur near human habitations, or where they may damage cultural resources such as historical buildings or pre-historical sites. Once these fires start, they often require indirect firefighting tactics to suppress, which complicates efforts to protect particular areas from burning. As a result, land managers and scientists are testing ways to reduce the chances of extreme fire behavior in this vegetation type where it occurs between Joshua Tree National Park and the communities of Yucca Valley and Joshua Tree (M. Brooks et al. unpublished data). They are comparing the effects of fire, mechanical blackbrush thinning, and chemical control of non-native annual grasses on subsequent fuel conditions, fire behavior, and plant community structure. The goal is to find tools that will allow managers to manipulate fuel characteristics to reduce fire hazards near areas identified for protection from fire, while having minimal negative ecological effects (such as promoting the dominance of invasive non-native plants).

Sagebrush and pinyon-juniper fuels are the primary focus of fuel management in the northern parts of the desert bioregion, especially in the Mono section. Sagebrush intermixed with perennial grasses is generally considered to be a greater fire hazard than the blackbrush communities described above. A century or more of fire exclusion and livestock grazing can also result in encroachment by pinyon juniper woodlands into sagebrush steppe (Miller and Tausch 2001). This has been documented in the northeast bioregion of California (Schaefer et al. 2003), and has also occurred where rainfall is relatively high in the desert bioregion at the ecotone of the Great Basin desert with the Sierra Nevada Mountains (Anne Halford, botanist, BLM-Bishop Field Office). Dense stands of mature trees in that area increase the chance of intense, stand-replacing, crown fire. Unfortunately, these same mature woodlands are desirable for use as homesites, especially in the Mono section, complicating the implementation of fuels management treatments and the protection of homes during fires. Millions of hectares are planned for fuels reduction in the western United States (http://www.fireplan.gov), and much will involve thinning of smaller size classes of pinyon and juniper trees to allows surface fuels to increase, and ultimately historically moderate intensity surface fires to return to the ecotone between pinyon-juniper woodlands and sagebrush steppe. Because very little is known about the effectiveness of these treatments in changing fire behavior or the potential ecological effects of these treatments, a research project was recently begun to quantifying the effects of pinyon and juniper thinning on subsequent fuel condition, fire behavior, and ecosystem variables at a site in northwestern Arizona (M. Brooks et al., unpublished data).

Where sagebrush and pinyon-juniper vegetation interface in the southern desert sections, they are either at high elevations far from major roads and human habitations, or they contain surface fuels of insufficient amount and continuity to carry fire. These stands only burn under extreme fire weather conditions. Analyses of aerial photographs and VTM survey data from the 1930s show no evidence of pinyon juniper expansion in the southern California desert region (R. Minnich, unpublished data). Accordingly, management of pinyon-juniper fuels is not advisable in this region, except were needed for specific cultural resource or safety reasons.

Fire Suppression

There is specific concern about the effect of fire suppression activities on the federally threatened desert tortoise where it occurs in low and middle elevation zones. More generally, fire suppression in desert wilderness areas became a significant issue after the California Desert Protection Act (1994) applied this designation to many new areas.

Wilderness areas often encompass mountain ranges in the desert bioregion, where locally high fuel loads from both native and non-native plants, and steep slopes, facilitate the spread of fire. Fire suppression options are generally more limited in these areas by the constraints outlined in wilderness management plans, and often the primary tactic is to wait for fire to spread down slope and attempt to stop it along pre-existing roads. This can result in large portions of desert mountains burning during a single event. The question is, which causes greater ecological damage, activities associated with aggressive fire fighting (e.g. construction of hand or bulldozer control lines, fire retardant drops) or large-scale, sometimes recurrent, fire occurring where fires were historically small and infrequent. Suppression is the appropriate action where fire frequency has been recently high in regional hotspots and non-native grass fire cycles have become locally established (Brooks and Esque 2002), where local populations of non-native plants may be poised to expand their range and landscape dominance following fire (mostly in the middle elevation ecological zone), or where there are other management reasons to exclude fire. Otherwise, a let burn policy for natural fires may be appropriate.

Postfire Restoration

Burn Area Emergency Rehabilitation (BAER) teams have developed postfire restoration/rehabilitation plans after the large fires that have recently occurred in the Mono section (e.g. Cannon and Slinkard fires), and further south in the desert bioregion at its ecotone with the transverse and peninsular ranges (e.g. the Juniper Complex and Willow fires). Much of the effort is focused on protecting watersheds from soil erosion, and one of the common tools is the seeding of rapidly growing plants. Postfire seeding may also be used to compete with and reduce the cover of invasive grasses associated with the grass-fire cycle. The idea is to replace highly flammable species such as cheatgrass with less flammable seeded species. Non-native perennial grasses such as crested wheatgrass (*Agropyron desertorum*) has been used to compete with and reduce cover of cheatgrass in Great Basin sagebrush steppe. However, there has been a recent move toward using more native species in postfire seeding, which may not have the same effect as non-native perennial grasses in suppressing the growth of non-native grasses such as cheatgrass. A current study is evaluating the relative effectiveness of non-native versus native perennial grasses to compete with and reduce cover of cheatgrass after fires in sagebrush steppe in the Mono section, and at sites in the Great Basin and Colorado Plateau (M. Brooks, unpublished data).

Fire Management Planning

One of the biggest challenges in fire management planning is determining desired future conditions to use as management goals. In cases where historical fire regimes can be reconstructed (e.g. ponderosa pine forest), the natural range and variation of historical fire regime characteristics may be the appropriate goal. However, management goals may be elusive where historical fire regimes cannot be easily reconstructed, such as in the desert bioregion where one must rely on inference of past conditions from current conditions. Fire histories alone may not be enough, however, when protection of specific natural or cultural resources are the primary management goal, or where plant invasions have changed the rules of the game. For example, if plant invasions have shifted fuel characteristics outside of their historically natural range of variation, then restoration of historical fire regimes may be impossible without first dealing with the invasive plants that are at the root of the problem (Brooks et al. in review). Although it appears that fire regimes, and at least woody fuel conditions, across much of the desert bioregion may be within their historical range of variation, it is difficult to quantify the impact that non-native plant invasions have had, aside from recognizing that fire regimes have been altered dramatically in some regional hotspots (Brooks and Esque 2002). Further complicating this process are the effects of potential future changes in rainfall patterns (Hereford et al. in review), and levels of atmospheric CO_2 (Mayeaux et al. 1994) and nitrogen deposition (Brooks 2003), on fuel conditions and fire regimes. All of these potential variables need to be considered when determining fire management goals in the desert bioregion.

The recent mandate by federal land management agencies to create fire management plans for all management units has resulted in a flurry of activity as new plans are drafted and old plans are revised. In many cases, plans developed for desert management units are supported by relatively few scientific studies, due to the paucity of fire research that has been conducted in the California desert bioregion. Decisions on when and where fuels should be managed, fires should be suppressed or allowed to bum, or post-fire restoration projects should be implemented are difficult to make given the limited data available. Recent reviews have attempted to provide land managers and others with current information on desert fire ecology and management (Brooks and Pyke 2001, Brooks and Esque 2002, Esque and Schwalbe 2002, Esque et al 2002, Brooks et al. 2003). Along these same lines, a primary purpose of this desert bioregion chapter is to provide additional information that can be used in the development of fire management plans in the deserts of southwestern North America.

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2.0 Fire Effects Monitoring

2.1 Objectives

The Mojave National Preserve fire management program goals and objectives aligned with the Preserve General Management Plan goals, Department of the Interior policy, National Park Service policy, and the National Fire Plan. The fire management program goals and objectives are listed in their entirety in the Fire Management Plan. Three of the goals are pertinent to fire effects monitoring or research, and monitoring objectives and variables are identified for each:

Fire Management Goal #2: Minimize negative impacts of fire and fire management activities on natural and cultural resources.

- Management Objective: Suppress all fires in designated critical tortoise habitat, and allow no more than 20 acres to burn annually March – October.
  - Monitoring Objective: Record (w/GPS) the perimeter of 100% of all reported fires > 1 acre.
  - Monitoring Variable: acres burned.
- Management Objective: Document and report all tortoise mortality caused by wildland fire use fire effects, suppression effects, or fuel treatments as described in the Biological Assessment/Biological Opinion for Desert Tortoise (Appendix A).
  - Monitoring Objective for Suppression Fires: Record all tortoise mortality caused by suppression actions.
  - Monitoring Objective for Fire Use Fires: Be 80% sure of recording immediate surface tortoise mortality from fire effects inside the perimeter of fire use fires.
  - Monitoring Variable: number of tortoises killed/injured
- Management Objective: In consultation with the Preserve's Cultural Resource Specialist, use fire management techniques and/or structural protection to protect 100% of documented, flammable, cultural resources from burning.
  - Monitoring Objective: Record all losses of documented, flammable cultural resources in all fires.
  - Monitoring Variable: number of historic resources burned.
- Management Objective: Contain each human caused ignition to less than 0.5 acre.
  - Monitoring Objective: Document 100% of the reported human caused ignitions in the Preserve.
  - Objective Variable: acres burned by fires of human origin

Fire Management Goal #5: Develop fire management planning strategies using science-based information and best professional judgment.

- Management Objective: Opportunistically collect short term or long-term change monitoring when a) a fire exceeds 100 acres or burns actively for more than 48 hours, or 2) a fire burns in one of the following vegetation types: interior chaparral, Rocky Mountain white fir, sagebrush steppe, or desert riparian woodland.
    - Monitoring Objective: Specific to the fire incident, the monitoring objective will be determined by fire researchers and Preserve resource management staff.
    - Objective Variable: To be determined specific to the fire incident.
- Management Objective: In consultation with the Preserve's resource management staff and fire researchers, pursue fire effects and/or fire ecology research opportunities for the questions identified in section 3 of this Appendix.
    - Monitoring Objective(s)/Research Objective(s): To be determined in the research proposal.
    - Objective Variable(s): To be determined in the research proposal.

Fire Management Goal #6: Recognize fire as a natural process within the Preserve.

- Management Objective: In areas designated as wildland fire use, allow naturally ignited fires to burn to their maximum size and duration that does not pose a threat to values at risk identified in the WFIP.
    - Monitoring objective: Document the fire perimeter and duration of 100% of all fires managed for fire use.
    - Objective variable: acres burned by fires managed for fire use
    - Objective variable: clock hours that fires managed for fire use burned from time of detection until declared out

2.2 Level 1 Monitoring: Environmental

Environmental monitoring provides the basic background information needed for decision-making. Based on the fire management objectives and fire environment of Mojave National Preserve, the focus of level 1 monitoring is the on-going collection of weather data, fuel data, and information regarding values at risk.

The two remote automated weather station (RAWS) are owned and maintained by the Bureau of Land Management, located within the Preserve boundary. The Mid-Hill RAWS was installed in 1991 and is located just east of the Mid-Hills campground in the approximate center of the Preserve, at 5400 ft. elevation. The Mojave River Sink RAWS was installed in 1988 and is located just inside the southwest corner of the Preserve, south of Zzyzx. Both stations are manufactured by Handar and the sensors are maintained by the Bureau of Land Management through the RAWS depot at the National Interagency Fire Center in Boise, Idaho. The stations collect, store and transmit hourly weather data to the National Interagency Fire Center via the Geostationary Operational Environmental Satellite operated by the National Oceanic and Atmospheric Administration. The data is fowarded to the Weather Information Management System for processing through the National Fire Danger Rating System to quantify and predict daily fire danger. The data is also transmitted to the Western Regional Climate Center in Reno, NV for storage.

The Hole-in-the-Wall weather station is a manual National Fire Danger Rating System (NFDRS) station and is operated by Hole-in-the-Wall Interagency Fire Center staff only during the fire season (April –October). Data is collected daily at 1400 hours, and is input into the Weather Information Management System by dispatchers at the Federal Interagency Communication Center. Actual and forecast fire danger indices are given during the daily 1600 hour weather forecast transmission by the Federal Interagency

There is currently not a complete fuel map for the Preserve. Fuel models can be interpreted from a digital vegetation map. An identified need for the Preserve is the development of a fuels map that includes fuel type and fuel load.

During development of the Fire Management Plan, existing geospatial data was compiled and analyzed to determine values at risk within the Preserve. These values are described in the Fire Management Plan under each of the Fire Management Units. To keep this information current, the Fire Management Officer will confirm the accuracy of the list with the Preserve's Science Advisor, Chief of Resource Management, Archaeologist, and Facility Manager annually.

2.3 Level 2 Monitoring: Fire Observation

Fire observation data is collected during fire incidents. Monitoring fire conditions calls for data to be collected on ambient conditions as well as on fire and smoke characteristics. These data are coupled with information gathered during environmental monitoring (level 1) to predict fire behavior and identify potential problems. Level 2 monitoring is composed of two stages. First, reconnaissance monitoring is the basic assessment and overview of the fire. Second, fire conditions monitoring is the monitoring of the dynamic aspects of the fire.

2.3.1. Reconnaissance Monitoring

Reconnaissance monitoring is required for all fires, including both suppression and wildland fire use fires. Reconnaissance monitoring is part of the initial fire assessment and the periodic revalidation of the Wildland Fire Implementation Plan. Recommended Standards (USDI National Park Service 2003) include:

- Initial Assessment: During this phase of the fire, determine fire cause and location, and monitor fire size, fuels, spread potential, weather, and smoke characteristics. Note particular threats and constraints regarding human safety, cultural resources, and threatened or endangered species or other sensitive natural resources relative to the suppression effort (especially fireline construction).

- Implementation Phase: Monitor spread, weather, fire behavior, smoke characteristics, and potential threats throughout the duration of the burn.
- Postburn Evaluation: Evaluate monitoring data and write postburn reports.

Data is collected from aerial or ground reconnaissance and recorded on the Initial Fire Assessment. Data is also recorded on FMH-1 (or -1A), FMH-2 (or -2A), and FMH-3 (or -3A). These forms can be taken from the Fire Monitoring Handbook at http://www.nps.gov/fire/fire/fir_eco_firemonitoring. The incident commander will decide who will collect the data and how frequently it will be collected during the incident. Each observation recorded must iinclue the observation date and time as well as the name of the person making the observation. The following information is collected:

- Fire name and number: Record the fire name and number assigned by the Federal Interagency Communication Center (dispatch).

- Fire cause (origin) and ignition point: Determine the source of the igniton and describe the type of material ignited.

- Fire location and size: Include a labeled and dated fire map with map coordinates. Where possible to use GPS, collect data in latitude/longitude and record the datum used. For fires larger than 0.5 acres, the final fire perimeter should be mapped using GPS.

- Logistical information: document routes, conditions, and directions for travel to and from the fire.

- .Fuel and vegetation description: describe the fuels array, composition, and dominant vegetation of the burned area. If possible, determine primary fuel model (Anderson 1982).

- Current and predicted fire behavior: describe fire behavior relative to the vegetation and the fire environment using adjective classes such as smoldering, creeping, running, torching, spotting, or crowing. Describe flame length, rate of spread, and spread direction.

- Potential for further spread: Assess the fire’s potential for further spread based on surrounding fuel types, forecasted weather, fuel moisture, and natural or artificial barriers.

- Current and forecasted weather: measure and document weather observations throughout the duration of the fire. Always record the location of the fire weather measurement and observation.

- Smoke volume and movement: assess smoke volume, direction of movement and dispersal. Identify areas that are or may be impacted by smoke.

- Resource or safety threats or constraints: consider the potential for the fire to impact adjacent landowners, threaten human safety and property, impact endangered species or cultural resources, or affect visibility on roadways. Report observations to the Incident Commander to facilitate notification of law enforcement personnel and/or resource advisors.

- A specific post-fire monitoring report is not required. Observations should be included in the fire documentation.

2.3.2 Fire Condition Monitoring

Fire condition monitoring is not required for all fires. At Mojave National Preserve, it is required for wildland fire use fires and fires that burn more than 1 acre in designated critical habitat for the desert tortoise. Data is used in completion of the Wildland Fire Implementation Plan – Stage II: Short-term Implementation Action and Wildland Fire Implementation Plan – Stae III: Long-term Implementation Actions. Data is collected from aerial or ground reconnaissance and recorded on FMH-1 (or -1A), FMH-2 (or -2A), and FMH-3 (or -3A). These forms can be taken from the Fire Monitoring Handbook at http://www.nps.gov/fire/fire/fir_eco_firemonitoring. The incident commander will decide who will collect the data and how frequently it will be collected during the incident. Monitoring tasks will most likely be assigned to the resource advisor if that person is qualified as a fire effects monitor (FEMO) or a fire observation specialist (FOBS), Each observation recorded must include the observation date and time as well as the name of the person making the observation. The following information will be collected:

- Topography: Measure percent slope using a clinometer. Determine aspect and report it in numerical compass direction. Determine elevation using maps or GPS.

- Ambient conditions: Either record information from existing weather stations or take field measurements using a belt weather kit. Record: dry bulb temperature, relative humidity, wind speed, wind direction, shading and cloud cover.

- Fire characteristics: Measure horizontal fire progression and report it as rate of spread in either chains/hour or meters/second. As appropriate, map the fire perimeter and calculate the area growth in a fire progression map. Record fire spread direction and describe as head, backing, or flanking for each area of the perimeter. Measure flame length (slanted vertical) and flame depth (horizontal).

- Smoke characteristics: Measure visibility as a change in visual clarity of an identified target at a known distance. Describe the smoke column, including direction and elevation. Record ground wind speed and direction. If warranted, a spot weather forecast may be requested from the National Weather Service and should include mixing height as well as transport wind speeds and direction.

- A specific post-fire monitoring report is required where fire condition monitoring occurs. This report should be completed within 5 days after the fire is declared out. The monitoring report should include: fire name, resource numbers and type (personnel and equipment), ignition source, holding strategy, chronology of fire behavior, chronology of significant events, chronology of smoke movement and dispersal, temperature, relative humidity, spot weather forecasts, fire progression, total acres burned, map of area burned, fire weather observation data sheets, fire behavior observation data sheets, smoke observation data sheets, and weather station data.

2.4 Level 3 and/or Level 4 Monitoring: Vegetation Change

There are currently no plans to systematically conduct level 3 short-term vegetation change or level 4 long-term vegetation change monitoring. However, there may be times that Mojave National Preserve would opportunistically monitor short-term or long-term changes as a result of fire. Specifically, we are interested in monitoring vegetation changes that result from fires that meet at least one of the following criteria:

- Exceed 100 acres or 48 hour in duration. The interest here lies in understanding the effects that these unusually large and/or long fires have on plant species composition.

- Burn in one of the following vegetation types: interior chaparral, Rocky Mountain white fir, sagebrush steppe, or desert riparian. All of these vegetation types are more common and widely studied in other areas but are relatively rare in the Mojave Desert. The interest here is in determining if these communities exhibit the same fire response here as they do in other areas.

As of 2004, there are several interagency agreements in place between the U.S. Geological Survey and the Pacific West Region. As immediate post-fire data collection is imperative to the monitoring needs described above, a task order under one of these interagency agreements is the most expeditious means to initiate monitoring. The primary partner for such monitoring will be the USGS Western Ecological Research Center, Las Vegas Field Station, located approximately 1.5 hours east of the Preserve. The research scientists at this facility have conducted much of the published research on fire effects/fire ecology of the Sonoran, Mojave, and Great Basin Deserts. As the Preserve lacks the capacity to conduct Level 3 or Level 4 fire effects monitoring, this research group will provide that service with NPS funding. Once a fire meets the criteria listed above and funds have been identified, the Preserve's Resource Management Specialist will communicate with the contracting officer, the contracting officers technical representative, the Preserve's Science Advisor, and the research scientists at USGS to process a task order and secure a research and collecting permit.

3.0 Fire Ecology and Fire Effects Research Needs

Fire ecology and fire effects research are fundamental to the science-based management of wildland fire. While there has been some research attention devoted to fire in the Mojave Desert, there remain many unanswered questions. The purpose of this section is certainly not to provide an exhaustive list of fire-related research needs, but rather to identify a few key research questions that were identified during the course of writing the 2004 Fire Management Plan for Mojave National Preserve. This list can provide a starting point for developing research proposals for securing research dollars to gain a better understanding of fire in the Mojave Desert in general, and Mojave National Preserve specifically. Inevitably, answers to such questions will lead to more questions and overtime a body of knowledge will be established that can guide future revisions of the Fire Management Plan.

1) What is the degree of departure from reference condition vegetation, fuels and disturbance regimes? This question should be addressed using Fire Regime Condition Class, an interagency, standardized tool and should be consistent with similar efforts conducted in the California Desert Fire Planning Unit.

2) In each fuel model, what is the natural fire return interval and where has this return interval been altered by invasive grasses? Does the magnitude of alteration vary by vegetation type, soil type, elevation, distance from roads, historical land use or other identifiable factors? What locations within the Preserve are most at risk for alteration in the next 20 years and what treatments might be used to mitigate that risk?

3) How is the quality of tortoise habitat affected by the presence of natural fire (ie. a fire use management prescription) and the absence of natural fire (ie. a suppression management prescription)? Such habitat affects might include changes in species composition, community structure, shrub density, forage availability, and nutrient availability. What other human or natural factors influence the magnitude and duration of that affect?

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