

Fire and dynamics of temperate desert woodlands in Joshua Tree National Park

Final Report

Contract No.

Richard A. Minnich
Department of Earth Sciences
University of California
Riverside, CA 92521
(909) 787-5515
richard.minnich@ucr.edu

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INTRODUCTION

Over the past three decades, temperate desert woodlands (TDW, Joshua Tree woodland, pinyon-juniper woodland, California Juniper-blackbrush scrub) in northwestern Joshua Tree National Park have experienced a series of wildfires that culminated in a complex of two simultaneous burns covering 15,000-acres in 1999. Studies of creosote bush scrub covering the Mojave and Sonoran Deserts suggest that the recent trend for extensive burning in arid shrublands of southeastern California is related to an increasing abundance of flash fuels produced by invasive exotic annual grasses introduced from the Mediterranean basin, notably *Bromus rubens* (Brown and Minnich 1986; Brooks 1999). These studies also suggest that changes in fire regime may destabilize creosote bush scrub and other desert shrublands covering low elevations of the Sonoran and Mojave Deserts. Similarly, in high deserts such as JTNP *Bromus tectorum* and *B. rubens* may have contributed to the recent fire outbreak in TDW. Alternatively, these areas have cooler climate, higher mean annual precipitation, and the vegetation has greater woody biomass than in lower deserts. It follows that the recent fire outbreak may be part of a normal fire cycle that is related to gradual cumulative successional build-up of woody fuels in these ecosystems rather than to fuels produced by invasive herbaceous species.

To address these questions, this study produces the following data sets on TDW in Joshua Tree National Park: (1) maps of vegetation before the fire outbreak, (2) a 100-year fire history and long-term population dynamics of TDW using repeat aerial photographs, and (3) data on post-fire successions based on chronosequence field sampling obtained in 1988. These data will contribute to toward a conceptual understanding of past fire regimes for the development of a fire management plan, addressing specifically the contribution of introduced species and native herbaceous fuels versus cumulative fuel build-up of woody fuels in the fire regime. The report concludes with recommendations on fire management.

THE STUDY AREA.

The study area covers the northwestern plateau of the Little San Bernardino Mountains from Covington Flat to Keys View Road and north to the paved road of Hidden Valley in northwestern Joshua Tree National Park (JTNP), 150 km east of Los Angeles. The study area includes a large expanse of uplifted alluvial plains (ca. 1,100 to 1,300 m) with intervening steep mountains rising above 1,500 m, with the highest summit at Quail Mountain (1,820 m). The range is an uplifted block that forms a precipitous southern escarpment along the San Andreas Fault. Substrate consists largely of extensive Mesozoic granite that weathers into irregular bedrock surfaces, such as the Wonderland of Rocks. A large body of dark-gray Precambrian Pinto Gneiss extends from Salton Sea View to Ryan Mountain and Sheep Pass. The Pinto Gneiss is highly foliated and weathers into smooth topographic surfaces.

Northwestern JTNP has a semiarid mediterranean climate due rain shadows of the Peninsular Ranges, with light rains from winter frontal storms and warm, dry summers except for thunderstorms of the North American monsoon. The mean annual precipitation ranges from 35 cm at Eureka Peak to 25 cm at Salton Sea View, and 20 cm at Queen Mountain and Hidden Valley (California, 1980). The high precipitation in the vicinity of Eureka Peak is due to the advection of Pacific Ocean moisture through San Geronio Pass.

METHODS.

The fire history and vegetation dynamics of TDW were reconstructed using time-series aerial photographs taken in 1942 (on file JTNP), 1953-54 (U.S. National Archives), 1968, 1971-74 (Department of Earth Sciences, University of California Riverside, 1998, and 1999 (on file, JTNP). Aerial photographs of the Riverside County portion of JTNP in 1983 (on file at the University of California Riverside) were not used, but were transferred to files at JTNP. Burns were recognized from the contrast between reflective ground in the burn site and surrounding dark vegetation. Other detailed evidences of fire include charred or fire-killed shrubs and trees, reduced stature and/or persistence of dead canopy in sprouting species, and unusually high mortality of overstory trees. Using a stereoscope, the 3-D perspective of the stereoscope permits the recognition of burn-scar geometries in complex terrain. Perimeter configurations are invariably random with respect to terrain, as opposed to the typically repetitious pattern of plant communities with slope and aspect.

Burns were also mapped using a second procedure in which repeat aerial photographs are georeferenced site-specifically to scale using a Zoom Transfer Scope (ZTS). Vegetation patches recorded on aerial photographs may be bare cliffs, bedrock outcrops, or local stands of thin vegetation on dry slopes. The comparison of time-series aerial photographs show that these features persist over time, while patches created by fire are ephemeral due to post-fire successions. The ZTS procedure also permits the comparison of pre-burn and post-burn vegetation and the determination of what kind of vegetation burned and fire severity based on how much above-ground canopy was denuded. Within each fire perimeter, polygons were drawn to delimit areas of stand-replacement burns, understory burns, and fire islands (unburned vegetation within perimeters).

The following maps were generated:

- Vegetation in 1974(classification and mapping criteria are given on Table 1). The map is shown two coverages: (1) and overstory layer of temperate woodlands, and (2) and understory layer of shrublands and grasslands.
- Fires before 1942 (not in JTNP records)
- Fire history, 1942-1998 shown with surviving unburned vegetation.
- Fire perimeters and fire severity in the 1999 fire complex.

The maps were entered into the JTNP Geographic Information System (GIS) on the computer GIS2.

The path and file names are:

Vegetation/overstory: \\GIS2\shapefile\fire\minnich\veg74_os.shp

Vegetation/understory: \\GIS2\shapefile\fire\minnich\veg74_us.shp

Fires < 1943: \\GIS2\shapefile\fire\minnich\fire_pre43.shp

Fires, 1942-98: \\GIS2\shapefile\fire\minnich\fire_42-98.shp

The 1999 fire: \\GIS2\shapefile\fire\minnich\fire_99.shp

The population dynamics of TDW were obtained by georeferencing time-series aerial photographs in 1952 and 1998, using the ZTS. On the ZTS the scenes were superimposed to scale, as recognized from the unique nearest-neighbor configurations of trees and shrubs within a stand. Because the same stems are being observed in both photo scenes, one can make site-specific estimates of stem densities and cover. Fundamental observations include: (1) the number of trees in common to both coverages; (2) recruitment of trees appearing in the recent photo coverage; (3) mortality of trees that disappear between old and new coverages; and (4) changes in cover due to population turnover and the grow of stems. Estimates were made of stem density and cover by species or vegetation type. Samples were obtained within 5 cm of photo nadir points to reduce the effect of parallax on estimates of cover. Specific sampling sites were selected using a random numbers table. The Joshua Tree could not be unequivocally identified on 1954 aerial photographs due to the combination of small stem canopies of the species and insufficient camera resolution. An exception was stands growing alone with limited shrub understory in basin floors. In these habitats, 21 samples were taken, using the above ZTS method for population changes since 1954.

To compare on-burn with off-burn vegetation, the vegetation was sampled at 13 locations using the line intercept and point-center quarter transects methods using the line intercept and point-quarter center methods in 1988. Differences across the fire boundaries are assumed to reflect fire mortality and post-fire succession processes.

VEGETATION DISTRIBUTIONS

In 1974, before the recent large fires, TDW dominated northwestern JTNP. Pinyon-juniper woodland covered steep rocky slopes above 1200 m from Quail Mountain northwestward along Smith Water Canyon ridge, from Keys View northwest to Juniper Flats, and above Covington Flats west to Eureka Peak (dominant species are listed in Table 1). Scattered stands descended the north-facing slopes of the upper southern escarpment facing the Coachella Valley. This type primarily covered granitic bedrock, and avoided metamorphic substrate except in the wettest part of the park near Eureka Peak. Joshua tree California juniper woodland was extensive on valley floors above 1300 m at Covington Flat, from Juniper Flats to southern Lost Horse Valley, and near Stubbe Spring. *Pinus monophylla* occurred with this type in upper Covington Flat, and locally elsewhere near the crest of the Little San Bernardino Mountains. Below 1300 m, valley floors were covered with monotypic stands of Joshua Tree, including Lost Horse Valley, Quail Wash, and Hidden Valley. California juniper was frequently the only tree species present on steep slopes on metamorphic rock units, including the northeast slope of Quail Mountain, the northeastern lower flank of the Keys View divide, slopes from Stubbe Spring to west of Juniper Flat, and the hills southwest of Cap Rock.

Understory vegetation in pinyon-juniper woodland was dominated by desert chaparral, especially along Key's View Ridge, Quail Mountain and on the slopes above lower and upper Covington Flats. Sparse desert scrub exists with pinyon-juniper woodlands on resistant granite bedrock slopes such as bedrock slopes immediately west of Lost Horse Ranger Station. Metamorphic bedrock slopes and most basins above 1300 m were covered with blackbrush scrub. Slopes and basins below 1300 m are covered with Mojave Desert Scrub. Level plains such Quail Wash, Lost Horse Valley and near the Randolph Ranch have local cover of galleta bunch grassland. Creosote bush scrub covered alluvial fans in lower Quail Wash and on the northern side of Hidden Valley.

TEMPERATE DESERT WOODLAND STAND CHARACTERISTICS IN 1998.

The density and cover of TDW varies with vegetation type, terrain, including slope and aspect. Summary data of temperate desert woodland types are given on Table 2 and Figures x to x (figures to be put into the report later).

The pinyon-juniper woodland type (*Pinus monophylla* dominant, with *Juniperus californica*) has the highest stem densities and canopy cover among all TDW types (mean densities, 123 ha⁻¹, cover 20%). Stands consist mostly conifers (98 ha⁻¹), with open cover of desert chaparral (23 stems ha⁻¹). The density and cover of chaparral is highest on slopes >20E. The cover of pinyon-juniper is significantly greater on north-facing than south-facing slopes. Pinyon-juniper densities in JTNP are about half that of pinyon-juniper woodlands in the nearby San Bernardino Mountains with a mean annual precipitation of 30-50 cm (Wangler and Minnich 1996). A few pinyon-juniper stands on Quail Mountain and near Eureka Peak develop crown closure, with tree cover locally reaching 50%. Desert chaparral stands without conifers occur entirely within recent burns, mostly on Quail Mountain. Shrubs persist by resprouting while conifers were fire-killed and had not recolonized this type. Desert chaparral densities in burns average 62 ha⁻¹. Pinyon-juniper-Joshua tree woodland (*Juniperus californica* dominant) form more open stands than pinyon-juniper woodlands. Conifers again dominate with average stem densities of 67 ha⁻¹. Chaparral understory is sparse. Joshua tree densities average 13 stems ha⁻¹ but the cover of this tree averages only 1%. Joshua tree densities are highest on slopes < 10E. Total stand cover averages 17%. Joshua tree-juniper woodland consists has even more open cover of *Juniperus californica* and *Yucca brevifolia*. Total stem densities average 52 ha⁻¹, about evenly divided between the two species. Conifer stem density increase with slope, while Joshua tree stem density decreases with slope. Tree cover averages only 7%, consisting mostly *J. californica*, with totals greatest on slopes > 10E. Joshua tree woodland consists of very open monotypic stands of Joshua tree (39 stems ha⁻¹), with little or no associated conifer or desert chaparral canopy. Stand cover averages only 2%. Monotypic juniper woodlands, which generally occur with blackbrush on steep slopes, have relatively high conifer densities of 58 stems ha⁻¹ and cover of 6%. Desert chaparral is almost absent in this type.

FIRE HISTORY.

The record of fires discussed below is recorded on the JTNP geographic information system.

Fires before 1952.

The recent outbreak of fires is not unprecedented. Aerial photographs in 1942 and 1954 record numerous landscape fire scars, all of which occurred before the 1942 photographs. Fires during this period were mostly < 300 acres, and scattered throughout northwestern JTNP. The largest fire was a 1500-acre burn in upper Covington Flat. Other burns are found near Eureka Peak, on Quail Mountain, and east of Keys View. There is a high concentration of small burns near the Randolph Ranch, south of Juniper Flats road, and 2.5 miles SSE of Cap Rock. The clustered spatial distribution of burns at some of these localities suggests that deliberate burning was practiced at the time these fires took place. JTNP records show that a 300-acre burn in 1942 northeast of Randolph Ranch occurred on July 4 and may have been related to the holiday. Two other burns of similar size occurred in the flats just N of Lost Horse Ranger Station. With the exception of the 1942 burn, all fires are undated. Landscape fire scars persist for decades possibly more than a century in TDW because of the large amount of time required for the maturation of trees. Give the very limit turnover and growth of TDW since 1954 aerial photograph cover, the mapped burns very likely occurred in the early 20th century or the late 19th century.

Fires from 1952-98.

Three small burns took place during the 1950s and 1960s, exclusively in Joshua Tree Woodland--galleta grass, one in Lost Horse Valley (1968) and two in Quail Wash (1967, 1968). The primary fire outbreak began with a 6,000-acre burn on Quail Mountain in 1978. Short-interval fire recurrences occurred within the 1978 perimeter in 1982, 1984 and 1987. Portions of Quail Wash were

burned in 1980 and 1985, these fires partly overlapping the burns of 1967 and 1968. Much of the Randolph Ranch flat was burned in 1979, and portions of the hill to the south of the flat were burned in 1984 and 1987. Small fires burned on Keys View Ridge in 1979, 1984, and 1987. Flames also spread into adjacent Lower Covington Flat, and all of Quail Wash. A small prescribed burn in 1989 in northern Lower Covington Flat was followed by another burn near the area in 1993. The ridge north of Smith Water Canyon was completely burned in 1995. Some of these burns were not recorded in JTNP files. The perimeters of other burns reconstructed from aerial photographs were improvements to field perimeters mapped real-time in the field in JTNP fire report forms.

Fire behavior.

Virtually all burns were "stand-replacement" fires, i.e., most above-ground canopy of TDW was fire-killed. The pattern of denudation depended on the vegetation. In pinyon-juniper woodland, flame lines were carried by shrub subcanopy and litter. Occasionally the tree canopy carried the flames as a "crown fire," especially dense stands such as those near Quail Mountain. Surviving unburned stands were almost exclusively "fire islands," missed solely by chance interactions between the spread of flame lines and weather, rather than intrinsic vegetation structure. Some islands occurred in fire-resistant bedrock slopes. In the aftermath of many burns, *Pinus monophylla* and *Juniperus californica* contained full canopy of scorched needle foliage, i.e., tree foliage was scorched but not burned. These species still perished because the heat of subcanopy flames fatally injured bole cambium due to the thin bark of these species. In addition, the low stature of canopy in contiguous contact with the burning shrub layer virtually insured fatal damage to foliage. Fires in blackbrush scrub were carried largely by the dominant *Coleogyne ramosissima*, a low shrub with dense fine branches providing fuel for flame lengths that may exceed 3 m. Flames normally resulted in total mortality of the overstory layer, mostly *Juniperus californica*. Junipers are typically small (< 5 m tall) with crowns contiguous with shrub understory. Surviving stands were exclusively fire islands. Fires in Joshua Tree woodland was carried by either blackbrush, Mojave Desert scrub, or galleta bunch grassland understory. While flame lengths were limited shrub and herbaceous biomass, in Joshua Trees the flames were propagated up the boles by dry leaf blades into the crowns. Unburned Joshua Tree canopy was found in areas of low intensity surface burns. Other stands survived within understory fire islands.

Fire report forms and repeat aerial photographs show that fuels burned in the 2500-ha burn of 1978 consisted of indigenous species. Pre-burn aerial photographs show that Quail Mountain was covered with mature pinyon-juniper forests, desert chaparral and subshrub subcanopy. The abundance of tree overstory suggests that the area had not sustained a mass burn in at least a century and probably much longer. Fire report narratives suggest an abundance of flashy fuels throughout the area due to heavy rains in the winter of 1977-78. However, there was no indication that introduced exotics *Bromus rubens* and *B. tectorum* were important fuels. Severe drought in 1975-77 very likely diminished the abundance of these exotics, as has been observed in the Riverside-Perris Plain during drought in 1988-90 and 1999-2003. An important fuel source may have been native wildflowers, especially species that cure during summer in the genera *Phacelia*, *Amsinkia*, *Cryptantha*, *Salvia (columbarie)*, and members of Brassicaceae. Abundant wildflowers were observed throughout the California deserts, including JTNP. In addition, heavy rains in 1977-78 may have increased the cover, productivity and fuel-load of subshrubs, such as *Ericameria cooperi*, *Encelia actonii*, *Eriogonum fasciculatum*, *Hymenoclea salsola*, *Salvia mojavnensis*, *Salazaria mexicana*, and *Viguiera deltoidea*. In Joshua Tree Woodland the spread of the 1978 burn may have been encouraged by the rapid growth of the native bunch grass *Hilaria rigida*.

The reburns on Quail Mountain in 1982, 1984 and 1987 occurred in years of above-normal precipitation. Extended periods of above normal-precipitation tends to increase the density and biomass of *Bromus* spp. Permanent plots set up in 1979, after a second consecutive wet year, recorded abundant cover of *Bromus rubens* (10-80% cover) at Lower Covington Flat, Johnny Lang Canyon, Quail Wash, Lost Horse Valley and Juniper Flat (Leary 1979). Hence, the proliferation of bromes and

post-fire-successional herbaceous forbs, due in part to the removal of woodland canopy, may have enhanced fire hazard following the 1978 burn. The importance of herbaceous fuel in the maintenance of flame lines is supported by the fact that the reburns largely remained within the 1978 burn, i.e., flames failed to carry into surrounding mature woodlands outside the 1978 perimeter where herbaceous cover was apparently limited. Personal ground photographs in JTNP during 1987-88, after two dry years, show that *Bromus tectorum* and *B. rubens* formed thin cover, but these annuals were scarce on steep slopes, especially in areas covered by mature pinyon-juniper woodland, desert chaparral, and blackbrush scrub. Denuded areas on Quail Mountain had continuous cover of *Bromus* spp. but slopes steeper than 20 degrees lacked significant cover of these species. No major fires occurred in JTNP during these years.

The large burn on the ridge north of Smith Water Canyon in 1995 correlates with heavy precipitation during an extended El Nino from 1991-95 (see below). While herbaceous cover was doubtless more abundant than normal, this area was also covered by mature pinyon-juniper woodland and desert chaparral, with comparable densities to stands burned in the 1978 Quail Mountain fire.

The three burns on Keys View Ridge (1979, 1982, 1987) were carried by dense blackbrush scrub. Aerial photographs show that the shrub layer was denuded. Blackbrush scrub can burn under high temperature and wind combined with low relative humidity despite the open spacing of plants. Herbaceous cover does not appear to have contributed to the spread of these fires. Most surviving vegetation consists of small fire islands.

The 1999 fire complex.

The May 1999-fire complex covered 15,000-acres from Lost Horse Valley across Quail Mountain to upper Covington Flat. The burn occurred during a large swing in precipitation variability in which heavy rains during the strong El Nino winter of 1998 were followed by severe drought the following year. Frequent rains from September 1997 to May 1998 resulted in extraordinary herbaceous cover, consisting both of native wildflowers, abundant *Bromus tectorum*, *B. rubens*, and dense cover of *Hilaria rigida*, especially on basin floors. Cured herbaceous cover from 1998 had not decomposed by the spring of 1999 because no significant rain or snow fell during the 1998-99 precipitation season. At the same time, the fuel moisture of woody shrubs and trees was greatly reduced by a year without significant precipitation.

Maps of vegetation damage in TDW within the 1999 fire perimeters show similar trends reported for earlier fires. These trends are discussed by vegetation type.

Pinyon-Juniper Woodland. Intense stand-replacement burns denuded mature stands in upper Covington Flat, southern Lower Covington Flat, and the south margin of Quail Mountain. The aftermath included burned shrublands and trees and abundant black and white ash, similar to chaparral fires. Flames were locally carried by tree canopy but more commonly by shrub fuels of desert chaparral on the slopes, and blackbrush scrub in flats. Herbaceous fuels, both *Hilaria rigida* and *Bromus tectorum*, were abundant on the alluvial plains of Lower- and Upper Covington Flats, and the plain north of Quail Mountain. There were few fire islands. When the 1999 fire spread into the 1978 burn (and fire recurrence areas) on the north-facing slope of Quail Mountain, fire behavior shifted to low intensity, creeping fires with numerous fire islands. Post-fire aerial photographs reveal little black ash in reburn areas and a black line boundary following precisely the 1978 fire perimeter dividing old growth pinyon-juniper woodland from post-1978 successional fuels. Since woody cover was lacking, it appears that abundant herbaceous cover maintained flame lines in the 1978 reburn zone. Low intensity flame lines in reburn zones are confirmed by the presence of green and scorched chaparral on the north slope of Quail Mountain and the Smith Water Canyon Ridge. The 1999 fire reverted to an intense stand-replacement mode in an old-growth pinyon-juniper fire island left by the 1978 burn, just north of Quail Mountain summit.

Juniper-Blackbrush scrub. Blackbrush scrub and associated woodland overstory of Joshua Tree and California Juniper was entirely denuded within the 1999 fire complex. A few small fire islands may be

found throughout the burn. One large island occurred on the south face of summit "4928," southwest of Cap Rock. This type was burned to the ground in Lower- and Upper Covington Flats, summit "4565" immediately south of Quail Springs Road, and at Juniper Flats. Abundant circles of white ash left by California Juniper that burned explosively suggest high fire intensities. Few Joshua Trees had green canopy after the fire on aerial photographs. However, there were numerous patches of green trees in upper Covington Flats, in the same area burned perhaps a century ago. Fuel levels in this area may have been lower than stands with no recorded fire history. While blackbrush was the primary fuel, abundant *Bromus tectorum* and *Hilaria rigida* enhanced the spread of flame lines in this type.

Joshua Tree Woodland. Mojave Desert scrub and galleta bunch-grassland, the primary fuels in this type, was also burned to the ground, with few fire islands. Most Joshua Tree overcanopy was fatally scorched. Surviving Joshua tree stands were most abundant in Lost Horse Valley, especially near the Randolph Ranch, where burns had occurred in 1968 and 1979. Most other areas of this type had not burned since records began. Green Joshua trees were observed locally in Juniper Flats, and in Hidden Valley north of Quail Springs Road. Exotic *Bromus tectorum* and *B. rubens* may have played the greatest role in this type because this invasive grass is most abundant where Joshua Tree Woodland is found--alluvial soils and valley floors. The interannual covariance of *Hilaria rigida* and *Bromus* spp. makes ambiguous the relative contribution of *Bromus* spp. in JTNP fire regimes.

POST-FIRE SUCCESSION.

Burns in the JTNP landscape appear as conspicuous gaps created by the denudation of the shrub layer and TDW overstory layer. Fire boundaries are accompanied by discrete shifts in species composition and biomass, even stands last burned over 50 years ago. Joshua Tree Woodland succession is dominated by resprouting of subshrubs and perennial grasses, while blackbrush scrub succession is associated with species replacements caused by high mortality of *Coleogyne ramosissima*. There has been only limited recolonization of arboreal species in either vegetation type. Differences in on-burn/off-burn densities from site to site reflect habitat variability rather than succession processes. Most sampling sites were reburned in the 1999 fire complex and were not resampled in this contract for lack of vegetation reestablishment. The characteristics of sampling sites are given in Table 3. Life history traits of dominant species are summarized on Table 4

Joshua Tree Woodland. Burns are dominated by vegetative reestablishment of perennial bunch grasses and subshrubs, with most species establishing pre-burn cover and stem density within ca. ten years (Tables 5-13). Perennial bunch grasses *Hilaria rigida* and *Stipa speciosa*, with scattered cover of *Ephedra nevadensis*, *Lycium cooperi*, and *Hymenoclea salsola* dominate all post-burn stands. When adequate moisture exists, *Hilaria rigida* develops general cover by sending up numerous stems that develop into tuft-like clumps from rhizomes emerging from subsurface root network. The clumps arise from tillers developing from the culms. *H. rigida* cover was 10-45% in 10-year burns, with tuft densities ranging 588 to 3699 stems ha⁻¹. *Stipa speciosa* and suffrutescent subshrubs form an additional 5-15% cover. In *Stipa speciosa*, apical meristems close to the ground in the interior of the clumps survive the flames that consume the leaves. Meristemic tissue is concentrated near the surface or underground where temperatures are relatively low during fire. Stems do not form rhizomes; hence clump growth and densities were not substantially greater than on off-burn samples. However, it locally increases ground cover as a consequences of tillers establishing new tufts outside the culm, increasing the surface area over which each culm occupies. The abnormally large size of *S. speciosa* tufts observed in burns may reflect the addition of soil nutrients from ash. *Ephedra nevadensis*, *Lycium cooperi*, and *Hymenoclea salsola*

persist by adventitious resprouting from root crowns. These species maintained preburn cover and densities because fire mortality is rare. Most recruitment in young burns consisted of *Hymenoclea salsola* and *Salazaria mexicana*. *Opuntia echinocarpa* and *O. ramosissima* had established new stems in >20 year stands from seed or vegetatively from fallen and transported joints dispersed apparently by animals.

Total site stem densities had reached preburn levels of 500 to 5495 stems ha⁻¹ because most resprouting and seedling establishment occurs during the first few growing seasons. The total cover of the subshrub layer increases for 20 years as a consequence of the growth of individual stems, ranging from 6-20% in burns of <6 years to 37-49% in burns 20-47 yr.

The most conspicuous vegetation change in Joshua tree woodland was the removal of *Yucca brevifolia*. Little is known about fire effects on *Y. brevifolia* other than that the species is intolerant of even low intensity fires. High fire mortality rates in *Y. brevifolia* reflects variable and unpredictable resprouting and heavy rodent browsing. Surviving individuals either resprouted by sending up "pups" from rhizomes along primary root axes extending radially from the root crown, or had sufficiently tall canopies to withstand the heat of ground fires. Resprouts were most frequent where the proportion of surviving stems was also large. Hence, it appears that the resprouting rates of *Y. brevifolia* are inversely related to fire intensity. *Y. brevifolia* recruitment appears to be slow but continuous. No seedlings or saplings were seen in burns < 10 years old and recruitment densities are typically <40 ha⁻¹ in older burns. Even the 46-yr Randolph Flat burn had only widely scattered saplings mostly < 3 m tall. These trends indicate that *Y. brevifolia* may reach pre-burn densities, cover and stature at time scales of a century.

Blackbrush Scrub. Post-fire succession in blackbrush scrub (Tables 14-17) is characterized by removal of overstory trees and species replacement in the understory layer. *Coleogyne ramosissima* is highly susceptible to fire because it is an obligate nonsprouter, and is slow to reinvade after fires (Webb et al. 1988). In JTNP denuded sites are colonized by abundant seedlings of suffrutescent shrubs, including *Hymenoclea salsola*, *Salazaria mexicana*, *Viguiera deltoidea*, and *Ericameria cooperi*. Obligate sprouters *Lycium* spp., *Ephedra* spp. persisted in the burns. Recruitment was apparently encouraged by the removal of *C. ramosissima*. The even-sized (even-aged) appearance of *Salazaria mexicana* suggests that stems established from post-fire seed caches. Seed of *Eriogonum fasciculatum* and *S. mohavensis* are also locally dispersed by animals. *E. fasciculatum* may have also established from seed caches. *Viguiera deltoidea* seedlings germinate apparently from wind dispersed seed from nearby unburned populations. Resprouting shrubs in BBS were similar to those in JTW (*Hilaria rigida*, *Stipa speciosa*, *Hymenoclea salsola*, *Ephedra nevadescens*, *Prunus fasciculata*, *Lycium cooperi*), and maintained preburn densities. The total cover and density of "resprouting" species was less than perennials establishing from seed. Surviving *Coleogyne ramosissima* were found on local unburned "fire islands" resulting from reticulate fire spread. The total understory cover varied from 20% in 6 year stands to 50% at 20 year stands.

Studies in Nevada (Callison et al 1985) show that burns were dominated by forbs and grasses for 12 yr. The shrub layer was dominated by resprouts of *Ephedra viridis*, *Prunus fasciculata*, and *Eriodictyon* spp. seedlings. Although seedlings of *Coleogyne ramosissima* often emerge from rodent caches, it is a weak competitor and recolonization is unpredictable. BBS stands as old as 21 years in JTNP show little reestablishment of *Coleogyne ramosissima*. The time required for complete recovery is unknown, and may be dependent on autogenic processes in which very long-lived species such as *C. ramosissima* accumulate biomass, stabilize productivity at maintenance levels, and have greater adaptation to environmental stress in later succession. Landscape fire scars in BBS recorded on 1942 and 1953 aerial photographs near the Randolph Ranch and Juniper Flats had disappeared by the 1998 aerial photograph coverage. This suggests that blackbrush recolonizes burns in ca. 50 to 100 years.

Yucca brevifolia and *Juniperus californica* sustained heavy mortality, although partially damaged *Juniperus californica* survived recent burns. While the smaller stature of *Yucca schidigera* exposed arboreal leaf blades to greater flame temperatures than in taller *Y. brevifolia*. *Y. schidigera* exhibited high

resprouting rates. Resprouts are characterized by basal rosettes emerging from subsurface rhizomes. Except for the removal of *Coleogyne ramosissima*, species differences between plots appear to be more due to habitat than to succession species changes. *Eriogonum fasciculatum* is abundant on shallow alluvium at Juniper flats, while *Viguiera deltoidea*, *Salazaria mexicana*, and *Ericameria cooperi* tend to be most abundant on rocky slopes. The only late successional recruitment in 20 year burns was the establishment of *Opuntia* spp., mostly seedlings or by vegetative establishment from dispersed joints. A few *Juniperus californica* seedlings were found on 20-yr Randolph plot. *Coleogyne ramosissima* seedlings were not recorded in any burn.

Pinyon-juniper woodland. The long-term succession of pinyon-juniper woodlands in the Mojave Desert has not been investigated. At two sites in JTNP (Tables 18 and 19, off-burn PJW was dominated by *Pinus monophylla* with scattered *Juniperus californica*, and understory of *Coleogyne ramosissima*, *Eriogonum fasciculatum*, *Quercus turbinella*, and *Ericameria linearis*. Post-fire succession was dominated by resprouting of *Q. turbinella*, *Stipa speciosa*, and seed cash establishment of *Ericameria linearis*, and *Arctostaphylos glauca*. Other species in burns include resprouts of *Ephedra californica*, *Nolina parryi*, *Prunus fasciculata*, and *Yucca schidigera*.

POPULATION DYNAMICS SINCE 1954

Because conifers and chaparral could not be systematically differentiated on 1953 black and white aerial photography, long-term changes in stem densities are shown as the sum of both conifers and desert chaparral. Burned TDW experienced large decreases in conifer cover because fires caused fatal injury to nonsprouting conifers, *Pinus monophylla* and *Juniperus californica* (summary data on Table 2). *Yucca brevifolia* also sustained large decreases in cover because few stems survive fire with green canopy and it is also a poor resprouter. Desert chaparral recovered rapidly due to resprouting of understory shrubs including *Quercus turbinella*, *Rhamnus crocea*, *Prunus ilicifolia*, and *Arctostaphylos glandulosa*, and the recruitment from seedbanks of *Arctostaphylos glauca*. Mortality rates of conifers and desert chaparral in the "desert chaparral" type averaged 61.5 stems ha⁻¹ and there was no detectable post-fire recruitment. There was a corresponding decline in total cover from 25.4% in 1954, to 6.3% in 1998. The mortality in burns was greater than in offburn areas by a factor of 5 to 10 in pinyon-juniper and juniper woodlands. Mortality was also greatest on steep slopes (> 30E) and north-facing exposures, primarily because stem densities are greatest in these terrain classes.

Outside the burn areas, all TDW types experienced small increases in stand density and cover. In general, recruitment exceeded mortality in 1954-1998; Increases in cover reflect the gradual growth of mature stems. The increase in stand densities ranged from 7 ha⁻¹ in pinyon-juniper-Joshua Tree woodland, to 0.5 ha⁻¹ in juniper woodland. Increases in stem density were also greatest on alluvial fans and plains dominated by pinyon-juniper-Joshua tree woodland and juniper-Joshua tree woodland, while increases were least on steep slopes covered by Juniper and pinyon-juniper woodland. In pinyon-juniper woodland, recruitment densities were uniform across all slope classes. Changes in cover were modest, seldom over 2%, reflecting the low productivity of these ecosystems. Joshua Tree stands in basin floors showed higher recruitment rates than other TDW species, with an average of 5.7 stems ha⁻¹ (Table 20). Mortality rates were also high at 2.0 ha⁻¹, leaving a net stand recruitment rate of 3.7 stems ha⁻¹ since 1954. There was little change in stand cover.

FIRE AND LONG-TERM DYNAMICS OF TEMPERATE DESERT WOODLANDS.

An assessment of the relationship between the recent fire and long-term ecosystem dynamics of TDW in Joshua Tree National Park is not straightforward. The fire outbreak of the past three decades may have been a stochastic perturbation, or may represent a shift in fire regime that may lead to long-term

directional (permanent) change. This question can be addressed in terms of two fuel models (Minnich 1998)--(1) fire occurrence is dependent on long-term cumulative fuel build-up [*cumulative fuel build-up model*] and (2) fire occurrence responds to short-term fluctuations in fuel load [*short-term fuel load model*].

Cumulative fuel build-up model.

On the basis of vegetation structure, this model applies best in pinyon-juniper woodland, desert chaparral, and blackbrush scrub. These communities gradually accumulate canopy (fuels) with time, similar to California chaparral. As a consequence, fire thresholds are achieved through successional processes that may span decades or centuries. Post-fire succession data show that it may require a century or longer or the reestablishment of tree cover in pinyon-juniper woodland (cf. Wangler and Minnich 1996) and juniper-blackbrush scrub growing on hillslopes habitats. The predominance of stand-replacement fires in 1978, 1995, and 1999--both in the tree layer and shrub understory--indicates that woody fuels carried these fires over most areas within their perimeters. Time-series aerial photographs 1942 show that pinyon-juniper woodlands have exhibited only slow turnover and growth over the past half century. Since the flammability of the tree layer varies little even at decadal time scales, these ecosystems may have already been in flammable states for decades or longer. While there was fire overlap between the 1978 and 1999 burns, only creeping fires took place in reburn zones, compared with intense stand-replacement fire behavior in old-growth stands. These trends support the *cumulative fuel build-up model* because creeping reburns which do not appear to be reversing shrubland succession which is a normal phase in early pinyon-juniper woodland succession; conifer establishment and development of canopy does not take place until after 50 years after fire (Wangler and Minnich 1996).

Short-term fuel load model. In the *short-term fuel load model*, the short time lag between fuel accumulation make entire landscapes flammable regardless of fire history, resulting in random patch turnover. Large annual production/decomposition-to-biomass ratios and low dry season fuel moisture enhance the variability of regional burning rates in response to allogenic factors such as weather. Because there is little time-dependence in fuel build-up, regional burning rates tend to increase with annual precipitation and annual productivity, and ignition rates. Fires cross over one another at random. The reburn cycles in Joshua Tree Woodland, especially stands with galleta bunch grassland, appears to support the *short-term fuel load model*. Portions of Quail Wash burned in 1967-68, 1980 and 1995. Randolph Flat burned in 1968, 1979 and 1999. Both sites have abundant galleta grass that recovers to preburn status within 10-years. Short-lived subshrubs are also an important component to this type. These trends support the model where fire occurrence is driven by short-term fluctuations in fuel production. However, while Mojave Desert scrub and galleta bunch grassland develop mature cover within decades, fire intervals may be far longer because the fuel hazard in understory fuels is diminished by drought. Fire intervals may be further delayed by stochasticity of fire starts.

Regional burning and precipitation variability. The importance of short-term productivity vs. long-term cumulative fuel buildup can be tested by correlating regional burning against precipitation. Interannual fluctuations in the rate of burning at JTNP appear to correlate with total annual precipitation, both in interannual and decadal time scales. Climatic data for Palm Springs, the only nearby long-term station (Table 22), shows that precipitation season totals (July to June) and 5-year running means were above-normal from 1940-41 to 1945-46. Subnormal precipitation followed for two decades until 1965, except for singular wet years associated with El Ninos in 1951-52 and 1957-58. A brief wet period from 1965-66 to 1968-69 was followed by renewed drought until 1976-77. Above-normal precipitation characterized the following two decades until 1995 that was interrupted by drought only from 1988-1991. With the exception of the El Nino of 1997-98, the region has been in extreme drought since 1996. At annual time scales, wet years frequently correlate with warm phase El Nino events, typical for the

southwestern United States and adjoining Baja California (Minnich et al 1993). Above-normal precipitation at decadal time scales correlate with the positive phase of the Pacific Decadal Oscillation (PDO) in the 1930s and 1940s, and again in the late 1970s through the mid-1990s; The drought in the 1950s and 1960s and since 1996 correlate with the negative phase of the PDO (Minobe 1997).

Most large burns are phased with above-normal precipitation. The 1978 Quail Mountain burn followed a winter with double-normal precipitation. The blackbrush burns of 1979 in Keys View Ridge and the Salton Sea escarpment southeast of Upper Covington Flat followed two consecutive winters of heavy precipitation. The Quail Wash burn of 1980 (mostly in galleta bunch grassland-Joshua Tree woodland) followed the wettest winter in historical record. The Quail Mountain reburns, and blackbrush burns on Keys View Ridge in 1982, 1984, and 1987 coincide with normal or above normal precipitation, including heavy rains of the 1982-83 El Nino and the wettest summer on record in 1984. Similarly the fires in 1993 and 1995 took place during abnormally heavy precipitation from 1991-92 to 1994-95. The fires in 1942, 1967 and 1968, all in Joshua Tree Woodland with galleta grass understory, also followed wet years. The 1999 fire complex was clearly triggered by heavy rains of the 1998 El Nino. Little burning occurred in JTNP during drought in 1970-77, 1988-91, and since 1999. The virtual absence of burns during the 1950s and 1960s also coincide with extended drought

U.S. Bureau of Land Management fire reports which record parallel outbreaks of fire in temperate desert woodlands in the northeast Mojave Desert during periods of above-normal precipitation (1978-85, 1991-95). During these periods large burns covering thousands of acres each occurred in the Granite Mountains, Providence Mountains, Mountain Pass, and Lanfair Valley. Almost no burning occurred during intervening years of subnormal precipitation.

In the south central Mojave Desert, the spatial extent of fires in creosote bush scrub correlates with mean annual precipitation recorded at Victorville (Table 23). Extensive burns occurred with above normal precipitation in 1980-85 and 1991-95. Few burns occurred during subnormal precipitation between 1985-91. Annual biomass can persist for two or more years. As a result, some fires occurred only after two or more consecutive wet years (1980), while other fires occurred in dry years immediately following wet years (1994). Least square regression correlations are highest ($r^2 = .36$) using a three-year running average. The correlation between annual precipitation and fire extent is weakened by the fact that fire is a discontinuous process dependent on stochasticity of ignitions and weather over short time scales (Minnich et al, in review).

There is insufficient data to address the importance of fuel models and precipitation variability to individual vegetation types of JTNP. It is hypothesized that temporal variation of burning rates in the park is due to fluctuations in fuel hazard of herbaceous annuals and perennial bunch grasslands, as well as subshrub cover, especially short-lived subligneous species such as *Hymenoclea salsola*, *Ericameria cooperi*, *Encelia actonii*, *Viguiera deltoidea*, *Salazaria mexicana*, and *Eriogonum fasciculatum*. These species increase growth in wet episodes, and experience dieback in drought with plant remains eventually breaking down by decomposition and disarticulation. Long-lived woody shrubs such as *Ephedra nevadensis*, *Lycium cooperi*, *L. andersonii*, and *Prunus fasciculata* may experience little interannual fluctuation in cover, but these species are seldom abundant in JTNP plant communities. Likewise, in JTNP subshrubs and herbaceous vegetation is important in pinyon-juniper woodland and blackbrush scrub because evergreen sclerophyllous conifers and chaparral seldom generate contiguous cover. Still, the importance of climate variability will be strongest in Joshua Tree Woodland, secondary in blackbrush scrub, and least in pinyon-juniper woodland. In the nearby San Bernardino Mountains, fire occurrence in dense pinyon-juniper woodland does not correlate with interannual precipitation variability (Wangler and Minnich 1996), and fire sequences exhibit nonrandom patch turnover characteristic of the cumulative fuel build-up model.

There is little evidence of widespread burning during the protracted period of heavy rainfall in the 1930s and 1940s. One explanation is that both *Bromus tectorum* and *B. rubens* were only making their primary invasion of the desert at this time (Table 21). Botanical collections show that both *Bromus rubens* and *B. tectorum* first invaded the California deserts during the 1930s (Table 21). The bromes and other

exotics became abundant after heavy rains in 1977 (F.C. Vasek, pers. comm.). The collections also suggest that these annual grasses were rare, or locally abundant along roads and disturbed fields. Cattle grazing from the late 19th to mid 20th centuries (Greene 1983) may have reduced fuel loads, and artificially reduced fire activity as late as perhaps 1950. In pinyon-juniper woodland and juniper-blackbrush scrub on hillslopes, it appears that herbaceous cover was insufficient to attract livestock to levels sufficient to modify these ecosystems, at least to levels sustained by Joshua Tree Woodland.

The stability of temperate desert woodlands.

While very recent burning rates extrapolated over long time scales would clearly degrade TDW ecosystems of northwestern JTNP, the area examined is too small and the fire history database is too short to determine long-term fire history and stability of TDW in Joshua Tree National Park. Broad scale fire records in southern California show that fire return intervals are sufficiently long enough for the reestablishment of these communities. The comparison of new maps of pinyon-juniper woodlands with maps produced by the California Vegetation Type Map (VTM) Survey of 1929-34 across southern California (Minnich and Everett 2001) show that the ranges of *Pinus monophylla* and *Juniperus californica* have not substantially changed over the past 70 years. Low primary productivity rates due to low average annual precipitation limit fire intervals to centuries, and gradual recolonization is seen in burns dating to the early 19th century (Wangler and Minnich 1996; Minnich and Everett 2002). Moreover, fire suppression does not appear to have much effect on TDW because fire intervals may be well within pre-suppression fire-free periods. The fire regime in pinyon-juniper woodland in the San Bernardino Mountains is similar to that in the Sierra Juarez and Sierra San Pedro Martir of northern Baja California, where fire control is not practiced (Wangler and Minnich 1996; Minnich and Chou 1997; Minnich et al. 2000).

Exotic annual invasions and long-term fire regimes.

While *Bromus rubens* and *B. tectorum* have proliferated in JTNP the past three decades, especially in Joshua Tree woodland, the role of invasive bromes in recent fire history is unclear. Abundant *B. tectorum* doubtless contributed to the spread of the 1999 fire complex, especially reburn zones. The hundreds of unburned fire islands in the 1978 reburn zone suggests that *Bromus tectorum* may have contributed to fire size (expansion of flame lines), but little to fire intensity and removal of woody biomass. However, the contribution of exotic annuals appears to have been limited in old-growth TDW in the burn. Similarly, the large fires in 1978 and 1995 were carried primarily by mature pinyon-juniper woodland and desert chaparral. The fires between 1979 and 1984 northwest of Keys View were carried by blackbrush scrub. Only low intensity creeping fires carried through the reburn zones of the 1978 fire, with insufficient flame lengths to even reverse the post-fire succession of desert chaparral. The reburns within the 1978 Quail Mountain indicate a post-fire feedback between reburn occurrence and early successional herbaceous cover. However, the feedback may eventually cease when herbaceous cover is replaced by woody cover.

The alternative hypothesis is that the abundance of herbaceous and subshrub fuels after prolonged rains in the 1998 El Nino was sufficient to support large fires with or without *B. tectorum*. The reburn feedback can be maintained by native herb cover and subshrubs.

Herb fires are not unprecedented in California deserts. Fossil charcoal in a seismic trench near the town of Mojave reveals that fires occurred periodically in creosote bush scrub over the past 7000 years, with the most likely fuel being indigenous wildflowers capable of curing into dry fuels (Minnich et al, in review). The JTNP has higher mean annual precipitation than at Mojave and very likely experienced periodic burning from herbaceous indigenous herbs in the same families as well as from increased production of perennial galleta bunch grasslands during the Holocene. Over long time scales, the magnitude and frequency of disturbance generated by invasive annuals may not be greater than that produced by native flower fields. Although *Bromus rubens*, *B. tectorum* and other invasive species have

recently increased the abundance of herbaceous fuels compared to that provided by indigenous annual forbs, exotic annuals are also subject to mass extirpations in droughts because they possess short seed life typical of grasses. In dry years, these grasses experience mass germination and mortality before reproductive maturity, resulting in local extirpations due to the destruction of the seed bank.

Recolonization may involve long seed dispersal lag times scaled in years or decades. *Bromus rubens* experienced widespread recruitment failure from drought in 1996 and 1997 and has rarely been seen since that time despite heavy rains in 1998. *B. tectorum* in JTNP may be experiencing extirpations as a result of the current drought. In contrast, native wildflowers survive unfavorable climate episodes persisting in seed banks as evidenced by their continuous presence in packrat midden records since 14 ka (Minnich et al, in review). Native forbs are able to produce abundant biomass from seed banks in every wet year. The interval between pulses of flammable exotic cover compared to that provided by forbs remains to be seen. Long-term monitoring will be vital to evaluate the dynamics of annual herbaceous cover and fire hazard.

MANAGEMENT RECOMMENDATIONS.

A fire management plan for JTNP must accommodate a fundamental observation that fires are rare in this semiarid region of low productivity. Site-specific return intervals occur at scales of centuries throughout the park. The recent distribution of fires also correlates with precipitation gradients. The northwestern JTNP evaluated in this report has the highest average annual precipitation and experiences the greatest rate of burning. Except for Ryan Mountain and Sheep Pass, fire records since 1942 show that areas to east and south have no history of mass burns, even in pinyon-juniper woodlands growing on summits rising above 1500 m southeast of Salton Sea View and near Cottonwood springs. All fires in these areas were spot burns that died out at less than a few acres.

For management planning, it can be assumed that fire hazard is limited every year in JTNP. The most significant concern for land managers will be short-term bursts of herbaceous productivity of wildflowers, galleta bunch grassland, and introduced *Bromus* species due to interannual precipitation variability. The importance of herbaceous productivity is greatest in Joshua tree woodland growing on the best soils in alluvial plains and basin floors. Drought appears to reduce fire hazard. It appears that low shrub live fuel moisture in subnormal precipitation years is less significant than decreases in herbaceous and subshrub biomass. Ecological monitoring sites will be vital to establish interannual fluctuations in fuel loads. Herbaceous species that leave little remnant fuel (e.g., poppies, desert dandelion, *Erodium cicutarium*) should be differentiated from which cure during summer drought (e.g., *Hilaria rigida*, *Bromus* spp., *Amsinkia* spp., *Phacelia* spp., *Salvia columbarie*).

Management options in pinyon-juniper woodland and blackbrush scrub should be based on the premise that fire occurrence is expected to be more dependent on cumulative fuel build up rather than interannual variability of precipitation and productivity. Moreover, the potential for large fires will be constrained by recent fire history because fire occurrence in time-dependent ecosystems is self-limiting and self-organizing in a patch mosaic over ecological time scales. Higher fire frequencies (greater density of fire events) will result in small fires, similar to that in Baja California (Minnich and Chou 1997). On the GIS fuel hazard can be assessed using time-since-fire maps with flammability increasing with time-since-fire. At present, the greatest fire hazard is found in old-growth pinyon-juniper woodland that has developed fuel loads approaching that of semiarid chaparral including stands on Eureka Peak, and locally on Keys View Ridge. Unfortunately, the time threshold to flammability is unknown because fire intervals are longer than the database. Interannual variation in fuel moisture of evergreen woody species may be insignificant because low average annual precipitation results in low levels during the summer dry every year, wet or dry. Fire hazard in Joshua Tree Woodland responds more to short-term fluctuations in herbaceous and subshrub productivity rather than to cumulative fuel build-up. Succession data indicate that mature cover of galleta bunch grassland and subshrubs is reached in ca. 20 years. This

understory may reach flammable thresholds only after wet years regardless of time-since-fire.

Because large fires are rare events in JTNP, a "let go" fire policy is a reasonable course of action. Most fire starts, whether established by lightning or anthropogenically, will die out as microburns. Very few ignitions will develop flame lines and most of these will take place in the northwestern part of the park. The fire history before suppression in 1954, before suppression was initiated, shows that most such burns seldom spread more than 300 acres. A burn will enlarge to scales of thousands of acres every few decades. Time-series statistics suggest that flame line burns have a higher probability of occurrence after wet years. Land managers should develop adaptive strategies based primarily on interannual variability in precipitation and ecological monitoring.

A "let go" policy also increases the probability that large fires will take place in normal fire weather risk states, with resulting fire spread rates and intensities also within normal range. Fire suppression affects the weather of fires because efforts to exclude fires have a nonuniform capacity to influence the spread of flame lines during the course of a fire. The effectiveness of suppression actions is dependent on the total energy output of fires. All fires begin at an (infinitely) low rate of energy release (the ignition). Energy levels then increase exponentially with increases in the length of perimeter flame lines. Suppression forces extinguish virtually all fires at the ignition stage, but has little effect on escaped large burns because energy release rates exceeds the energy of suppression by orders of magnitude. However, the weather risk state influences energy levels at the ignition stage, with ignitions in severe weather (and high energy release states) having the highest probability of expanding past early suppression. Because the continuity of weather operates in time scales of days (in association with synoptic shifts in atmospheric circulation), the weather characteristics of major fires have a high probability of resembling the weather risk state at the ignition. It follows that ignition stage suppression selectively nonrandomizes the occurrence of large fires to severe weather risk-states compared to chance. This results in more severe, larger fires and greater damage to vegetation. Most large fires in southern California have coincided with Santa Ana winds and heat waves, as opposed to normal slope-wind weather conditions in Baja California, Mexico where there is no fire suppression.

Four specific recommendations are given toward policy implementation:

- "Let go" fires should be monitored, mapped and entered into fire history GIS records for both updating the patch mosaic (time-since-fire) status of the park, and for scientific investigation.
- In rare wet years JTNP may experience extraordinary growth of herbaceous cover, especially *Bromus* spp., as in the case of the 1998 El Nino winter. When such conditions develop, JTNP should consider the use of livestock *ad hoc*, to remove herbaceous fuels as a mitigation against catastrophic fire. It is vital to annual monitor herbaceous and subshrub biomass.
- Planned burns in the park appear to be unnecessary due to low primary productivity of JTNP ecosystems. In fact they may be counterproductive. For example, a burn in 1989 at Lower Covington Flat was self-defeating as blackbrush scrub was replaced by dense *Bromus* grassland, with even greater fire hazard. Planned burns should be restricted to scientific experiments.
- To implement a "let go" policy, the burden of action should be placed on the suburban population living along the margin of JTNP. This is a process of public education and homeowner responsibility. Among the cities bordering the park, the only significant urban interface with abundant wildland fuel is along the southern border of Yucca Valley. (The vegetation near the towns of Joshua Tree, Twenty-nine Palms, and in the northern Coachella Valley is too sparse to carry fire.) A principle of policy for implementation is simple: The cause of fire is the vegetation (which stores organic energy). Homeowners should maintain fuel safe properties by mitigating the vegetation. Options include removing or thinning natural vegetation, irrigation of ornamental vegetation, and construction of non-flammable structures. Protection of suburban communities should not be the responsibility of JTNP who instead should be "curators" of a natural process that mediates ecosystem dynamics in a semiarid climate.

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Table 1. Vegetation classification for northwestern Joshua Tree National Park.

Temperate Desert Woodland coverage.

Pinyon-Juniper Woodland (\$5% conifer cover, *Yucca brevifolia* #1% cover; *Pinus monophylla* dominant, *Juniperus californica*)

Pinyon-Juniper-Joshua Tree Woodland (\$5% conifer cover; *Juniperus californica* dominant, *Pinus monophylla*; *Yucca brevifolia* \$1% cover).

Joshua Tree-Juniper Woodland (*Juniperus californica* \$1% cover; *Yucca brevifolia* \$1% cover).

Juniper Woodland (*Juniperus californica* \$1% cover).

Joshua Tree Woodland (*Yucca brevifolia* \$1% cover)

Understory shrub and grassland coverage (understory cover \$5% cover; types delineated by dominance).

Desert chaparral (*Quercus turbinella*, *Arctostaphylos glauca*, *A. glandulosa*, *Prunus ilicifolia*, *Rhamnus crocea*, *Ericameria cooperi*, *Yucca schidigera*; \$5% cover).

Blackbrush scrub (*Coleogyne ramosissima*, *Yucca schidigera*, *Stipa speciosa*, *Ephedra viridis*, *E. nevadescens*, *Lycium andersonii*, *L. cooperi*, *Eriogonum fasciculatum*, *Ericameria cooperi*; \$5% cover).

Mojave Desert Scrub (*Hymenoclea salsola*, *Lycium andersonii*, *L. cooperi*, *Ephedra viridis*, *E. nevadescens*, *Eriogonum fasciculatum*, *Yucca schidigera*, *Krameria*, *Tetradymia*, *Salazaria mexicana*; \$5% cover).

Creosote bush scrub. (*Larrea tridentata*, and species of Mojave Desert Scrub.

Galleta bunch grassland. (*Hilaria rigida*, *Stipa speciosa*, *Hymenoclea salsola*, *Ephedra viridis*, *E. nevadescens*, *Lycium cooperi*, *L. andersonii*, *Opuntia engelmannii*, *Yucca schidigera*; \$5% cover)

Table 2. Stand density and cover of temperate desert woodlands of Joshua Tree National Park¹.

Vegetation Type (1998)/ Stand property	Pinyon-Juniper Woodland	Pinyon-Juniper-Joshua tree Woodland	Juniper Joshua Tree Woodland	Joshua Tree Woodland	Juniper Woodland	Desert Chaparral
Density (ha-1)						
Conifer	98.2	65.9	24.9	0.3	57.5	2.3
Desert Chaparral	24.9	4.3	0.2	0	1.6	60.9
Joshua Tree	1.2	13.6	27.5	39.0	1.5	0.1
Conif+chap, 1998	123.1	70.2	25.0	0.3	59.1	62.9
Conif+chap, 1954	119.3	63.0	21.5	1.8	59.7	124.3
1954-1998, conif+chap						
Mortality	1.8	0.9	0.7	0.1	2.1	61.5
Recruitment	4.5	8.1	4.3	0	1.6	0
Cover (%)						
Conifer	16.9	13.5	4.3	0	5.9	0.7
Desert chaparral	3.2	1.1	0.1	0	0.2	5.6
Joshua Tree	0	1.9	2.1	1.5	0	0
Conifer+chap, 1998	20.1	14.6	4.4	0	6.0	6.3
Conifer+chap, 1954	20.0	13.5	4.1	0	6.1	25.4

1. The vegetation samples for all types except desert chaparral were unburned during 1954-98. Desert chaparral stands were former pinyon-juniper woodlands in 1954. Burned stands in other types had no temperate desert woodland cover.

Table 3. Life traits of dominant shrubs and trees observed in Joshua Tree National Park.

Species/Life trait	Resprouter ¹	Estimated resprout rate (% of individuals) ²	Seed dispersal	Disturbance stimu-lated germination	Long-lived (life span > 100 years)
<i>Acacia greggii</i>	X	H	Fauna		X
<i>Ambrosia dumosa</i>	No	-	Wind		
<i>Coleogyne ramosissima</i>	No	-	-		X
<i>Encelia actonii</i>	No	-	Wind	X	
<i>Ephedra nevadensis</i>	X	H	Fauna		X
<i>Eriogonum fasciculatum</i>	No	-	Wind, fauna	X	
<i>Hilaria rigida</i>	R	H	Wind		X
<i>Hymenoclea salsola</i>	X	M	Wind	X	
<i>Juniperus californica</i>	No	-	Fauna		X
<i>Larrea tridentata</i>	F	L	Wind		X
<i>Lycium andersonii</i>	X	H	Fauna		X
<i>Lycium cooperi</i>	X	H	Fauna		X
<i>Opuntia acanthocarpa</i>	No	-	Vege disp, fauna.		X
<i>Opuntia echinocarpa</i>	No	-	Vege disp, fauna		X
<i>Opuntia ramosissima</i>	F	M	Vege disp, fauna		-
<i>Pinus monophylla</i>	No	-	Fauna		X
<i>Prunus fasciculata</i>	X	H	Fauna		X
<i>Salazaria mexicana</i>	X	M	-	X	
<i>Ericameria cooperi</i>	No	-	Wind	X	
<i>Stipa speciosa</i>	S	H	Wind		
<i>Viguiera deltoidea</i>	No	-	Wind	X	
<i>Yucca brevifolia</i>	F	L	In situ		X
<i>Yucca schidigera</i>	R	H	In situ		X

1. X, root crown sprouter
F, facultative sprouter
R, rhizome sprouter
S, Intercalary resprouting from stolens

2. H, high--ca. 100% of stems
3. M, medium--30-100% of stems
4. L, low--< 30% over stems

Table 4. Characteristics of vegetation sampling sites.

Site/vegetation	Year of fire	Elev (m)	Aspect/slope (E)	Landform	Lat.	Long.
<i>Joshua Tree Woodland</i>						
Hidden Valley	1987	1210	W 5	alluvium	34 02	116 48
Northwest Entrance to Hidden V.	1984	1109	S 3	alluvium	34 03	116 47
Sheep Pass	1982	1360	SE 2	alluvium	34 00	116 52
Quail Wash South	1980	1070	E 8	alluvium	34 04	116 43
Quail Wash North	1980	1050	E 5	alluvium	34 05	116 43
Randolph Ranch	1979	1280	E 2	alluvium	34 00	116 49
Quail Mountain	1978	1170	N 10	alluvium	34 02	116 45
Quail Wash	1967	1090	NE 5	alluvium	34 04	116 43
Lost Horse Valley	1942	1270	E 4	alluvium	34 01	116 49
<i>Blackbrush scrub</i>						
Sheep Pass	1984	1370	S 20	rocky slope	34 00	116 52
Juniper Flat	1979	1440	N 5	thin alluvium	33 58	116 46
Quail Mountain	1978	1260	NE 25	rocky slope	34 02	116 46
Randolph Ranch	1968	1350	S 7	thin alluvium	34 00	116 49

Table 5. Estimated cover and density of desert perennials in a one-year old burn in Joshua Tree Woodland at Hidden Valley in 1988.

Species	Cover (%) Off-burn	Cover (%) On-burn	Density (ha ⁻¹) Off-burn	Density (ha ⁻¹) On-burn
<i>Coleogyne ramosissima</i>	6.6	0	632	0
<i>Ephedra nevadensis</i>	3.4	0.3	316	18
<i>Hilaria rigida</i>	8.6	0.1	1581	0
<i>Hymenoclea salsola</i>	6.4	0.3	527	9
<i>Lycium cooperi</i>	3.9	2.0	211	18
<i>Opuntia echinocarpa</i>	0.3	0	105	0
<i>Opuntia ramosissima</i>	0.9	0	211	0
<i>Stipa speciosa</i>	0.2	0	105	0
<i>Yucca brevifolia</i>	6.4	2.6	211	9
Total	37.6	5.9	4217	81

Table 6. Estimate cover and density of desert perennials in a 4-year old burn in Joshua Tree Woodland at the northwest entrance to Hidden Valley in 1988.

Species	Cover (%) Off-burn	Cover (%) On-burn	Density (ha ⁻¹) Off-burn	Density (ha ⁻¹) On-burn
<i>Ephedra nevadensis</i>	2.0	0	70	0
<i>Hilaria rigida</i>	17.4	5.7	1540	588
<i>Hymenoclea salsola</i>	2.3	1.2	140	100
<i>Larrea tridentata</i>	6.7	1.4	210	50
<i>Lycium andersonii</i>	2.4	1.0	70	50
<i>Lycium cooperi</i>	0	2.9	0	100
<i>Opuntia acanthocarpa</i>	0	0.1	70	0
<i>Opuntia echinocarpa</i>	1.4	0	70	0
<i>Opuntia ramosissima</i>	0	0.5	0	0
<i>Salazaria mexicana</i>	5.5	0.9	420	75
<i>Stipa speciosa</i>	2.0	0	70	0
<i>Yucca brevifolia</i>	4.4	0.4	140	0
<i>Yucca schidigera</i>	0	0	0	75
Total	45.8	14.4	2800	1024

Table 7. Estimated cover and density of desert perennials in a 4-year old burn in Joshua Tree Woodland at Sheep Pass 1988.

Species	Cover (%) Off-burn	Cover (%) On-burn	Density (ha ⁻¹) Off-burn	Density (ha ⁻¹) On-burn
<i>Coleogyne ramosissima</i>	1.3	0	55	0
<i>Ephedra nevadensis</i>	1.3	0.6	110	50
<i>Eriogonum fasciculatum</i>	0	1.0	0	0
<i>Hilaria rigida</i>	10.8	11.7	938	1100
<i>Hymenoclea salsola</i>	5.7	6.8	497	600
<i>Larrea tridentata</i>	16.0	0.8	386	0
<i>Lycium andersonii</i>	0	0	0	100
<i>Lycium cooperi</i>	0	4.0	0	0
<i>Opuntia acanthocarpa</i>	0.5	0	0	0
<i>Salazaria mexicana</i>	0	0.6	0	0
<i>Stipa speciosa</i>	2.0	0.2	55	0
<i>Yucca brevifolia</i>	2.5	0	165	0
Total	39.1	21.5	2206	2029

Table 8. Estimated cover and density of desert perennials in a 8-year old burn in Joshua Tree Woodland at Quail Wash south in 1988 (site reburned in 1995).

Species	Cover (%) Off-burn	Cover (%) On-burn	Density (ha ⁻¹) Off-burn	Density (ha ⁻¹) On-burn
<i>Acacia greggii</i>	1.3	3.8	140	137
<i>Ephedra nevadensis</i>	4.3	2.3	420	137
<i>Eriogonum fasciculatum</i>	0.7	0.5	0	0
<i>Hilaria rigida</i>	15.8	45.4	1190	3699
<i>Hymenoclea salsola</i>	1.2	8.5	140	1096
<i>Lycium andersonii</i>	0	1.2	0	137
<i>Lycium cooperi</i>	0.6	4.0	70	274
<i>Opuntia echinocarpa</i>	0.6	0	70	0
<i>Opuntia ramosissima</i>	1.5	0	0	0
<i>Stipa speciosa</i>	0.7	2.0	70	0
<i>Yucca brevifolia</i>	15.8	0	280	0
Total	44.8	62.3	2800	5495

Table 9. Estimated cover and density of desert perennials in a 8-year old burn in Joshua Tree Woodland at Quail Wash North in 1988 (site reburned in 1995).

Species	Cover (%) Off-burn	Cover (%) On-burn	Density (ha ⁻¹) Off-burn	Density (ha ⁻¹) On-burn
<i>Acacia greggii</i>	1.6	2.5	88	39
<i>Ephedra nevadensis</i>	2.5	1.4	176	39
<i>Hilaria rigida</i>	6.2	5.9	352	510
<i>Hymenoclea salsola</i>	0.8	0	264	0
<i>Larrea tridentata</i>	20.3	0	352	0
<i>Lycium cooperi</i>	0.2	2.4	88	59
<i>Opuntia echinocarpa</i>	0.4	0	88	0
<i>Yucca brevifolia</i>	11.4	0.2	176	19
Total	53.6	13.5	1766	784

Table 10. Estimated cover and density of desert perennials in a 9-year old burn in Joshua Tree Woodland at Randolph Ranch in 1988 (site reburned in 1999).

Species	Cover (%) Off-burn	Cover (%) On-burn	Density (ha ⁻¹) Off-burn	Density (ha ⁻¹) On-burn
<i>Ephedra nevadensis</i>	4.2	3.7	116	170
<i>Hilaria rigida</i>	30.1	14.5	957	850
<i>Hymenoclea salsola</i>	0	1.3	0	0
<i>Lycium cooperi</i>	0.6	0	29	34
<i>Opuntia echinocarpa</i>	0	0.6	0	68
<i>Yucca brevifolia</i>	4.2	2.2	58	68
<i>Yucca schidigera</i>	0	3.5	0	0
Total	11.4	28.0	1157	1369

Table 11. Estimated cover and density of desert perennials in a 10-year old burn in Joshua Tree Woodland at Quail Mountain in 1988 (site reburned in 1999).

Species	Cover (%) Off-burn	Cover (%) On-burn	Density (ha ⁻¹) Off-burn	Density (ha ⁻¹) On-burn
<i>Acacia greggii</i>	3.6	3.4	62	27
<i>Coleogyne ramosissima</i>	3.0	1.2	0	0
<i>Ephedra nevadensis</i>	9.5	3.5	279	67
<i>Eriogonum fasciculatum</i>	3.8	2.8	124	0
<i>Hilaria rigida</i>	0.6	1.5	0	0
<i>Hymenoclea salsola</i>	17.1	2.9	434	40
<i>Opuntia echinocarpa</i>	2.8	0	31	0
<i>Opuntia ramosissima</i>	2.9	0	62	0
<i>Salazaria mexicana</i>	0.5	1.7	31	27
<i>Salvia mojavnensis</i>	0	9.7	0	54
<i>Stipa speciosa</i>	0	8.7	0	307
<i>Yucca brevifolia</i>	8.5	1.1	124	0
Total	53.4	35.8	1242	535

Table 12. Estimated cover and density of desert perennials in a 21-year old burn in Joshua Tree Woodland at Quail Wash in 1988 (site reburned in 1999).

Species	Cover (%) Off-burn	Cover (%) On-burn	Density (ha ⁻¹) Off-burn	Density (ha ⁻¹) On-burn
<i>Acacia greggii</i>	1.5	1.7	117	145
<i>Coleogyne ramosissima</i>	2.2	0	117	0
<i>Ephedra nevadensis</i>	4.1	0.9	351	145
<i>Eriogonum fasciculatum</i>	0.5	0	0	0
<i>Hilaria rigida</i>	40.4	38.8	2574	4350
<i>Hymenoclea salsola</i>	7.8	0	702	0
<i>Lycium cooperi</i>	1.7	1.7	117	145
<i>Opuntia echinocarpa</i>	1.5	1.0	468	0
<i>Opuntia ramosissima</i>	0.1	0	0	0
<i>Salazaria mexicana</i>	1.7	0	0	0
<i>Stipa speciosa</i>	0.5	4.5	0	725
<i>Yucca brevifolia</i>	6.1	0	117	0
Total	59.8	49.3	4694	5813

Table 13. Estimated cover and density of desert perennials in a 46-year old burn in Joshua Tree Woodland at Lost Horse Valley in 1988 (site reburned in 1999).

Species	Cover (%) Off-burn	Cover (%) On-burn	Density (ha ⁻¹) Off-burn	Density (ha ⁻¹) On-burn
<i>Acacia greggii</i>	0.5	0	81	0
<i>Ephedra nevadensis</i>	4.0	3.7	324	572
<i>Hilaria rigida</i>	15.0	34.7	1053	3289
<i>Hymenoclea salsola</i>	0.3	4.1	0	429
<i>Lycium cooperi</i>	0.5	2.5	0	143
<i>Lycium andersonii</i>	0.5	0	81	0
<i>Opuntia echinocarpa</i>	1.1	1.0	81	0
<i>Opuntia ramosissima</i>	0.2	0	0	0
<i>Stipa speciosa</i>	4.8	5.6	567	1144
<i>Salazaria mexicana</i>	0	1.0	243	0
<i>Yucca brevifolia</i>	4.2	0.2	162	0
<i>Yucca schidigera</i>	0	0.2	0	0
Total	40.9	48.8	3268	5739

Table 14. Estimated cover and density of desert perennials in a 6-year old burn in blackbrush scrub at Sheep Pass in 1988.

Species	Cover (%) Off-burn	Cover (%) On-burn	Density (ha ⁻¹) Off-burn	Density (ha ⁻¹) On-burn
<i>Ambrosia dumosa</i>	4.4	6.4	762	1392
<i>Coleogyne ramosissima</i>	15.8	0.2	2159	0
<i>Encelia actonii</i>	2.0	3.0	127	706
<i>Ephedra nevadensis</i>	0.7	0	254	0
<i>Eriogonum fasciculatum</i>	0	0	0	0
<i>Hilaria rigida</i>	1.7	0	0	0
<i>Hymenoclea salsola</i>	0	0	0	0
<i>Juniperus californica</i>	0	0	0	0
<i>Lycium cooperi</i>	1.4	0	0	0
<i>Opuntia acanthocarpa</i>	0	0	0	0
<i>Opuntia echinocarpa</i>	1.4	0	0	0
<i>Prunus fasciculata</i>	0	0	0	0
<i>Salvia mojavnensis</i>	0	0	0	116
<i>Salazaria mexicana</i>	0	0.9	0	116
<i>Stipa speciosa</i>	3.5	6.1	508	1750
<i>Viguiera deltoidea</i>	3.1	1.4	127	464
<i>Yucca brevifolia</i>	6.1	0.9	127	0
<i>Yucca schidigera</i>	5.6	0.2	381	0
Total	42.1	23.6	5102	4630

Table 15. Estimated cover and density of desert perennials in a 9-year old burn in blackbrush scrub at Juniper Flat in 1988.

Species	Cover (%) Off-burn	Cover (%) On-burn	Density (ha ⁻¹) Off-burn	Density (ha ⁻¹) On-burn

<i>Ambrosia dumosa</i>	0	0	0	0
<i>Coleogyne ramosissima</i>	30.6	0	2062	0
<i>Encelia actonii</i>	0	0	0	0
<i>Ephedra nevadensis</i>	3.8	1.1	290	160
<i>Eriogonum fasciculatum</i>	1.4	9.9	194	800
<i>Hilaria rigida</i>	0	0.7	0	80
<i>Hymenoclea salsola</i>	0	0	0	0
<i>Juniperus californica</i>	8.9	0	194	0
<i>Lycium cooperi</i>	0	2.5	0	0
<i>Opuntia acanthocarpa</i>	0	0	0	0
<i>Opuntia echinocarpa</i>	0.3	0	0	0
<i>Prunus fasciculata</i>	0	0	0	0
<i>Salvia mojavnensis</i>	0	0	0	0
<i>Salazaria mexicana</i>	0	13.6	0	632
<i>Stipa speciosa</i>	6.0	12.3	970	1520
<i>Viguiera deltoidea</i>	0	0	0	0
<i>Yucca brevifolia</i>	1.2	0	97	0
<i>Yucca schidigera</i>	0	0	381	0
Total	47.4	38.7	3906	3193

Table 16. Estimated cover of desert perennials in a 10-year old burn in blackbrush scrub at Quail Mountain in 1988 (reburned in 1999).

Species	Cover (%) Off-burn	Cover (%) On-burn	Density (ha ⁻¹) Off-burn	Density (ha ⁻¹) On-burn
<i>Ambrosia dumosa</i>	0	0	0	0
<i>Coleogyne ramosissima</i>	34.1	1.7	672	0
<i>Encelia actonii</i>	0	0	0	0
<i>Ephedra nevadensis</i>	0.7	2.5	0	87
<i>Eriogonum fasciculatum</i>	0	0.9	0	0
<i>Hilaria rigida</i>	5.4	0	96	0
<i>Hymenoclea salsola</i>	1.5	0	0	0
<i>Juniperus californica</i>	10.0	0	72	0
<i>Lycium cooperi</i>	0	2.6	0	58
<i>Opuntia acanthocarpa</i>	0	0	0	0
<i>Opuntia echinocarpa</i>	0	0	0	0
<i>Prunus fasciculata</i>	2.3	6.0	0	145
<i>Salvia mojavnensis</i>	0	2.9	0	87
<i>Salazaria mexicana</i>	0	3.4	0	377
<i>Stipa speciosa</i>	0	11.1	0	319
<i>Viguiera deltoidea</i>	0	15.3	0	0
<i>Yucca brevifolia</i>	3.9	0	48	0
<i>Yucca schidigera</i>	2.3	2.5	72	87
Total	59.9	49.5	960	1160

Table 17. Estimated density of desert perennials in a 2-year old burn in blackbrush scrub at the Randolph Ranch in 1988 (reburned in 1999).

Species	Cover (%) Off-burn	Cover (%) On-burn	Density (ha ⁻¹) Off-burn	Density (ha ⁻¹) On-burn

<i>Ambrosia dumosa</i>	0	0	0	0
<i>Coleogyne ramosissima</i>	16.9	0.7	949	0
<i>Encelia actonii</i>	0	0	0	0
<i>Ephedra nevadensis</i>	1.7	1.2	146	65
<i>Eriogonum fasciculatum</i>	1.6	0.9	146	0
<i>Hilaria rigida</i>	18.7	16.3	1022	975
<i>Hymenoclea salsola</i>	1.7	10.0	73	585
<i>Juniperus californica</i>	3.3	0.6	73	0
<i>Lycium cooperi</i>	1.0	3.2	0	65
<i>Opuntia acanthocarpa</i>	1.7	2.3	146	190
<i>Opuntia echinocarpa</i>	0	0	0	0
<i>Prunus fasciculata</i>	0	0	0	0
<i>Salvia mojavnensis</i>	0	0	0	0
<i>Salazaria mexicana</i>	0.9	7.1	73	650
<i>Stipa speciosa</i>	0	0	0	0
<i>Viguiera deltoidea</i>	0	0	0	0
<i>Yucca brevifolia</i>	4.3	1.0	73	0
<i>Yucca schidigera</i>	7.1	7.1	146	260
Total	54.7	50.8	960	2790

Table 18. Estimated cover and density of desert perennials in a 9-year old burn in pinyon-juniper woodland in Juniper Flat in 1988.

Species	Cover (%) Off-burn	Cover (%) On-burn	Density (ha ⁻¹) Off-burn	Density (ha ⁻¹) On-burn
<i>Acacia greggii</i>	0	0	0	0
<i>Acamptopappus</i>	0	0	0	0
<i>sphaerocephalus</i>			0	0
<i>Arctostaphylos glauca</i>	0	0.8	50	0
<i>Chrysothamnus nauseosus</i>	0	0	50	0
<i>Coleogyne ramosissima</i>	14.1	0	0	0
<i>Ephedra nevadensis</i>	1.5	0	0	0
<i>Ericameria linearis</i>	16.1	8.1	150	200
<i>Eriogonum fasciculatum</i>	2.5	0	300	50
<i>Hymenoclea salsola</i>	0	0	0	0
<i>Juniperus californica</i>	6.8	0	50	0
<i>Opuntia acanthocarpa</i>	0	0	0	0
<i>Opuntia ramosissima</i>	0	0	0	0
<i>Pinus monophylla</i>	9.5	0	0	0
<i>Prunus fasciculata</i>	0	1.0	0	0
<i>Quercus turbinella</i>	33.2	13.0	50	0
<i>Salazaria mexicana</i>	0	0	0	0
<i>Salvia mojavnensis</i>	0	0	0	0
<i>Stipa speciosa</i>	2.0	4.3	300	100
<i>Yucca brevifolia</i>	1.4	0.1	0	0
<i>Yucca schidigera</i>	0	0.2	0	0
Total	75.1	30.4	1000	350

Table 19. Estimated cover and density of desert perennials in a 10-year old burn in pinyon-juniper woodland on Quail Mountain in 1988 (reburned in 1999).

Species	Cover (%) Off-burn	Cover (%) On-burn	Density (ha ⁻¹) Off-burn	Density (ha ⁻¹) On-burn
<i>Acacia greggii</i>	0	0.6	0	0
<i>Acamptopappus</i>	0	0	0	200
<i>sphaerocephalus</i>			0	0
<i>Arctostaphylos glauca</i>	5.4	1.7	0	600
<i>Chrysothamnus nauseosus</i>	0	0	0	0
<i>Coleogyne ramosissima</i>	17.4	4.8	300	0
<i>Ephedra nevadensis</i>	1.6	0	0	0
<i>Ericameria linearis</i>	2.7	3.9	50	350
<i>Eriogonum fasciculatum</i>	9.2	0	0	0
<i>Hilaria rigida</i>	0	0	0	0
<i>Hymenoclea salsola</i>	0.2	0	0	0
<i>Juniperus californica</i>	5.4	0	0	0
<i>Lycium cooperi</i>	0	0	0	0
<i>Opuntia acanthocarpa</i>	1.6	0	0	50
<i>Opuntia ramosissima</i>	0.5	0.6	0	0
<i>Pinus monophylla</i>	14.7	0	0	0
<i>Prunus fasciculata</i>	0	0.6	0	0
<i>Quercus turbinella</i>	3.1	4.3	0	0
<i>Salazaria mexicana</i>	0.5	0.4	0	0
<i>Salvia mojavnensis</i>	0	0	0	1250
<i>Stipa speciosa</i>	3.8	5.4	0	0
<i>Viguiera deltoidea</i>	0	0	0	0
<i>Yucca brevifolia</i>	2.2	0.1	0	0
<i>Yucca schidigera</i>	0	0.8	0	0
Total	62.5	35.9	350	2250

Table 20. Population data of monotypic Joshua tree stands (n=21)

Year/variable	Density (stems ha ⁻¹)	Cover (%)
1954	13.6	1.23
recruitment	" 6.6	"0.68
mortality	5.7	-
1998	"3.5	-
	2.0	1.29
	"1.3	"0.76
	16.2	
	"6.9	

Table 21. Botanical collections of *Bromus rubens* in the Mojave Desert before 1940.

Collection/Herbareum ¹	Year	Location
<i>Bromus rubens</i>		
Parish (RSA)	1887	Fort Tejon
Jepson 5468 (JEPS)	1913	New York Mountains
Epling (LA)	1925	Palmdale
Abrams 11709 (LA)	1927	Head of Antelope Valley
Wolf 1546 (RSA)	1928	South side of Antelope Valley
Epling (LA)	1930	Argus Mountains (Death Valley)
Duran 3420 (RSA, UC)	1933	Between Mojave and Palmdale
Duran M40 (UC)	1933	Silver Canyon, White Mountains
Clokey, Anderson 6518 (UC)	1935	North of Barstow
Axelrod 286 (UC)	1935	Deep Creek, San Bernardino Mtns.
Jepson 18348 (JEBS)	1937	Mitchells Cavern
Beal 299, 304 (JEBS)	1937	Providence Mountain
Yates 6496 (UC)	1937	Antelope Valley
Jepson 19692, 19754 (JEPS)	1940	Panamint Mountains
<i>Bromus tectorum</i>		
Peirson 4543 (RSA)	1924	Victorville
Abrams 11744 (RSA, CAS)	1927	Antelope Valley between Neenach and Fairmont
Jones (RSA)	1929	Hesperia
Jenson 375 (UC)	1934	Phelan
Axelrod 271 (UC)	1935	Deep Creek, San Bernardino Mountains

1. RSA, Rancho Santa Ana Botanical Garden. Claremont, California.

2. JEPS, Jepson Herbareum. University of California, Berkeley.

3. LA, University of California, Los Angeles.

4. UC, University of California, Berkeley.

Table 22. Total annual precipitation and departures from the mean at Palm Springs¹.

Year/burns (*)	Precipitation (inches)	PON ²	5-year running ave. PON ²	Year/burns (*)	Precipitation (inches)	PON ²	5-year running ave. PON ²
1940-41 ³	11.81	221	158	1972-73 ³	4.26	80	73
1941-42*	9.64	181	150	1973-74	3.99	75	60
1942-43	11.85	223	176	1974-75	2.35	44	53
1943-44	11.17	210	183	1975-76	4.56	86	62
1944-45	3.99	75	182	1976-77 ³	6.86	129	83
1945-46	6.93	130	164	1977-78 ³	11.37	213	110
1946-47 ³	2.95	55	139	*	7.40	139	122
1947-48	3.89	73	109	1978-79*	16.21	304	175
1948-49	5.91	111	89	1979-80	2.52	47	167
1949-50	1.40	26	79	1980-81	3.85	72	156
1950-51	1.58	30	59	1981-82*	8.76	164	146
1951-52 ³	8.50	160	80	1982-83 ³	8.31	156	149
1952-53	7.29	137	93	1983-84*	2.97	56	99
1953-54	6.48	122	95	1984-85*	5.98	112	112
1954-55	4.44	83	106	1985-86	4.53	85	114
1955-56	2.69	51	110	1986-87 ³	5.78	108	104
1956-57	4.01	75	94	*	1.72	32	79
1957-58 ³	7.19	135	93	1987-88	1.43	27	73
1958-59	2.42	45	78	1988-89	4.93	92	69
1959-60	3.95	74	76	1989-90	7.65	143	81
1960-61	1.56	29	72	1990-91	12.96	243	108
1961-62	2.54	48	66	1991-92 ³	2.57	48	111
1962-63	2.68	50	49	*	8.89	167	128
1963-64	6.24	117	64	1992-93 ³	1.31	25	114
1964-65	3.40	64	62	*	1.37	26	91
1965-66 ³	9.92	187	93	1993-94	9.41	176	116
1966-67*	5.69	107	105	1994-95 ³	0.79	15	109
1967-68*	4.78	89	113	*	1.74	32	82
1968-69 ³	7.61	143	118	1995-96	4.52	84	95
1969-70	4.05	76	120	1996-97	0.37	6	63
1970-71	2.21	42	91	1997-98 ³	4.20	70	44
1971-72	1.34	25	75	1998-99*			
				1999-2000			
				2000-01			
				2001-02			
				2002-03			

1. Source. US Department of Commerce (1936-2003). Climatological Data, California.

2. PON, percent of normal. Cumulative five-year running average.

* Major burns (> 100 ha) in Joshua Tree National Park.

3. Warm phase El Nino events.

Table 23. Annual precipitation at Victorville, California and annual area burned in the south central Mojave Desert (mm).

Year	Annual precipitation (cm)	Area burned (ha) ¹
1977-78	32.7	
1978-79	22.7	
1979-80	24.2	6398
1980-81	7.4	1630
1981-82	15.2	403
1982-83	32.7	2354
1983-84	9.4	1470
1984-85	17.8	0
1985-86	18.5	63
1986-87	14.3	197
1987-88	15.6	1855
1988-89	9.3	57
1989-90	8.1	19
1990-91	18.8	0
1991-92	23.9	647
1992-93	34.0	2034
1993-94	9.0	4939
1994-95	18.8	824
r ² 3-yr running ave.		.36

1. from Minnich et al, in review.