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Precipitation regime classification for the Mojave Desert: Implications for fire occurrence

Jerry Tagestad [a, *], Matthew Brooks [b], Valerie Cullinan [a], Janelle Downs [a], Randy McKinley [b]

[a] *Pacific Northwest National Laboratory, United States*
[b] *U.S. Geological Survey, United States*

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ABSTRACT

Long periods of drought or above-average precipitation affect Mojave Desert vegetation condition, biomass and susceptibility to fire. Changes in the seasonality of precipitation alter the likelihood of lightning, a key ignition source for fires. The objectives of this study were to characterize the relationship between recent, historic, and future precipitation patterns and fire. Classifying monthly precipitation data from 1971 to 2010 reveals four precipitation regimes: low winter/low summer, moderate winter/moderate summer, high winter/low summer and high winter/high summer. Two regimes with summer monsoonal precipitation covered only 40% of the Mojave Desert ecoregion but contain 88% of the area burned and 95% of the repeat burn area. Classifying historic precipitation for early-century (wet) and mid-century (drought) periods reveals distinct shifts in regime boundaries. Early-century results are similar to current, while the mid-century results show a sizeable reduction in area of regimes with a strong monsoonal component. Such a shift would suggest that fires during the mid-century period would be minimal and anecdotal records confirm this. Predicted precipitation patterns from downscaled global climate models indicate numerous epochs of high winter precipitation, inferring higher fire potential for many multi-decade periods during the next century.

1. Introduction

The Mojave Desert is situated in the southwestern United States and encompasses over 13 million hectares. As a warm desert ecoregion, the magnitude and seasonality of precipitation are critical drivers of ecosystem processes. Precipitation controls the foundations of food webs, the evolution of physical landscapes, and the dynamics of nutrient cycles and disturbance regimes (Rowlands, 1995; Rundel and Gibson, 1996). Understanding past, current and potential future precipitation regimes is critical in evaluating how climate change may affect Mojave Desert ecosystems.

The amount of precipitation varies with elevation, and to some degree latitude, which profoundly affects vegetation composition across the ecoregion. The lowest elevations which receive the least precipitation are currently dominated by creosote bush (*Larrea tridentata*) and saltbush (*Atriplex spinifera*). Middle elevations include mixed woody scrub, Joshua tree woodlands (*Yucca brevifolia*), and blackbrush (*Coleogyne ramosissima*). The highest, most mesic regions are dominated by sagebrush (*Artemisia tridentata*), pinyon-juniper woodland (*Pinus monophylla* and *Juniperus osteosperma*), and interior chaparral (*Adenostoma fasciculatum*, *Arctostaphylos glauca*, *Ephedra* spp.). These vegetation distributions have changed substantially during the Holocene, moving downslope and upslope within multi-century periods of high and low precipitation (Koehler et al., 2005).

Seasonality of precipitation also varies from east to west in the Mojave Desert (Rowlands et al., 1982), with different regions experiencing different ratios of winter versus summer precipitation (Rowlands, 1995; Hereford et al., 2004, 2006). Longitude 117°W, near Barstow, California has been cited as the general dividing line between winter-dominated precipitation to the west and bimodal winter/summer precipitation to the east (Hereford et al., 2006).

Precipitation amounts have varied significantly during the 20th Century, with an early-century wet period, mid-century drought, and late century wet period (Huning, 1978; Hereford et al., 2006).

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* Corresponding author.
E-mail address: jerry.tagestad@pnnl.gov (J. Tagestad).

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These multi-decadal periods of above or below average precipitation correspond with precipitation regime shifts between positive and negative phases of the Pacific Decadal Oscillation (PDO) (Hereford et al., 2006). During the positive PDO phase, El Niño years of the El Nino-Southern Oscillation (ENSO) are more frequent resulting in a greater number of above-average precipitation years in the Mojave Desert (Hereford et al., 2006). In contrast, during the negative PDO phase, La Niña years are more prevalent resulting in more years of low precipitation in the Mojave Desert.

Precipitation patterns affect the type and amount of vegetation produced in arid regions (Noy-Meir, 1973 Holmgren et al., 2006; Holden et al., 2007), which in turn affects fire regimes (Brooks and Matchett, 2006). Long-term drought or above-average precipitation periods can have landscape-scale effects on the health and distribution of perennial plant species (Beatley, 1979) and the frequency and size of fires (Brooks and Minnich, 2006). Short-term increases in winter and summer precipitation can have an even greater effect on the likelihood of fire. High winter precipitation creates ephemeral flushes of herbaceous biomass resulting in continuous fuelbeds that promote the spread of fire. High summer precipitation brings thunderstorms with accompanying lightning and high winds which contribute to the ignition and spread of fires (Brooks and Matchett, 2006). Cumulative years of higher than normal precipitation also appear to have an effect on the potential for fire. This is especially a concern in areas invaded by annual grasses which exhibit a profound response to increased cool-season precipitation, The 2005 Mojave Desert fire season, which burned an area equal to 132% of the total area that burned during the previous 25 years, was preceded by three extremely high precipitation years, suggesting that multiple years of high precipitation can have a cumulative effect on the accumulation of fuels (Brooks and Matchett, 2006).

Climate change in southwestern North America is a concern for many including those concerned with municipal water supply, agricultural stability, and wildfire potential. Most climatic futures predicted by global climate models (GCMs) point to a warmer future (Cole et al., 2010). Research by Seager et al. (2007) predicted an increase in evapotranspiration rates which could also lead to lower soil moisture levels. This view is generally supported by a study centered on California and Nevada, where temperatures are predicted to rise while precipitation is predicted to be level (Pan et al., 2011). Recent analysis of regional climate models (RCMs) over southwest North America (with improved handling of eddy moisture fluxes over complex terrain such as that found in the Mojave) indicate increased winter precipitation in the future for southern California and portions of Nevada within the Mojave ecoregion (Gao et al., 2012, 2014).

Although we recognize past 20th Century trends of early-century wet, mid-century drought, and late-century wet precipitation periods over the entire Mojave Desert, and the general trend of increasing bimodal precipitation seasonality from west to east (Hereford et al., 2004, 2006), we do not know how precipitation regimes (amount and seasonality) have varied over both space and time within this bioregion. The first objective of this study was to evaluate the spatial clustering of precipitation magnitude and seasonality to identify and map precipitation regime boundaries during each of the three distinct precipitation epochs of the last century.

Current fire science theory predicts that the number, size, and frequency of fires should increase with both annual precipitation and summer precipitation (Brooks and Matchett, 2006; Brooks and Minnich, 2006). Current theory also predicts that fire regime variables should vary among vegetation types in the lower, middle, and upper elevation zones of the Mojave Desert (Minnich, 2003; Brooks and Matchett, 2006). The second objective of this study was to test these hypotheses by comparing the relationship between fire number, size, and frequency among vegetation types with precipitation regime boundaries during the late-century wet period.

Future climate predictions call for generally hotter and drier conditions in the Mojave Desert, although predictions vary based on modeling assumptions (Seager et al., 2007; Pan et al., 2011 and Gao et al., 2012). The implications of climate change for fire occurrence are not uniform across the Mojave Desert because prevalence of fire differs among elevational zones (Brooks and Matchett, 2006) and potentially among precipitation regimes. The third objective of this study was to evaluate the possible implications of a range of climate scenarios on the potential effects on fire in the ecoregion.

2. Methods

2.1. Study region

The Mojave Desert is the northernmost desert within the Warm Deserts ecoregion of North America. It is situated between the Great Basin to the north, Colorado and Arizona plateaus to the east, Sonoran Desert to the south, and Sierra Nevada and southern California mountains to the west (Fig. 1). The mountains to the west create a large rain shadow that is largely responsible for the Mojave Desert being an arid ecoregion. Smaller mountains and complex topography within the ecoregion create mini-rain shadows that affect patterns of precipitation.

Between 1976 and 2010 there were 227 fires in the Mojave Desert greater than 405 ha (1000 acres). These fires burned a total of 758,477 ha (1,874,230 acres) with most of the burned area occurring in the middle elevation zones receiving sufficient precipitation for growth of fuels. Since precipitation is the most critical component for promoting vegetation productivity, we did not assess the effect of elevated temperature and its relationship to fire.

2.2. Data sources

To define the spatial distribution of precipitation regimes, we used data from the Parameter-elevation Regressions on Independent Slopes Modal (PRISM) product produced by the PRISM Climate Group at Oregon State University (for a complete discussion of the model, see: Daly et al. (1997)). These publically-available datasets provide average monthly precipitation on a uniform 1-km grid interpolated from weather station data. To develop a classification of precipitation regimes, we analyzed the period from 1971 to 2010 because it contained both wet and dry intervals for which we had precise geospatial data on fire occurrence. We acquired the 30-year normal PRISM data for the period 1971–2000. This dataset represents the monthly average precipitation at 800 m grid cell resolution. We acquired monthly data for 2001–2010 at 4000 m resolution and resampled all the datasets to 1000 m before combining them via weighted average to represent monthly 40-year normals from 1971 to 2000.

2.3. Identifying and mapping precipitation regimes

Random samples of pixels and the associated rainfall data were taken to reduce spatial correlation in the data that is naturally occurring from local and regional precipitation patterns. Systematic grid-sampling with a random start assures all areas are represented in proportion to their size. We evaluated our random sampling approach by iterating the random samples multiple times ($n = 10$) and visually assessing spatial coverage by mapping the point locations of the samples. The results were consistent across the ten iterations and represented the sub regions proportionally.