Southern California Desert Habitats

Climate Change Vulnerability Assessment Synthesis

An Important Note About this Document: *This document represents an initial evaluation of vulnerability for desert habitats based on expert input and existing information. Specifically, the information presented below comprises habitat expert vulnerability assessment survey results and comments, peer-review comments and revisions, and relevant references from the literature. The aim of this document is to expand understanding of habitat vulnerability to changing climate conditions, and to provide a foundation for developing appropriate adaptation responses.*

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Executive Summary

There are three deserts in southern California: the Mojave Desert, the Colorado Desert (a subdivision of the larger Sonoran Desert), and the less well-known San Joaquin Desert, which historically encompassed 28,493 km^2 and included much of the San Joaquin Valley, Carrizo Plain, and Cuyama Valley. These desert ecosystems contain the highest temperature extremes in the United States; topographical relief in these desert ecosystems ranges from 86 m below sea level in Death Valley up to 3,300 m above sea level in the Panamint Range (Randall et al. 2010).

The relative vulnerability of desert habitats in southern California was evaluated to be moderate by habitat experts[1] due to moderate sensitivity to climate and non-climate stressors, moderate-high exposure to projected future climate changes, and low-moderate adaptive capacity.

Sensitivity and Exposure	<u>Climate sensitivities</u>: Precipitation, soil moisture, low stream flows, drought, extreme heat events <u>Disturbance regimes</u>: Wildfire, flooding <u>Non-climate sensitivities</u>: Invasive and other problematic species

Desert habitats are sensitive to climate drivers that exacerbate the already hot and dry conditions, enhancing vulnerability for many species that already exist close to their physiological limits. Climate drivers and disturbances (e.g., changes in precipitation, flooding, wildfire) have the potential to significantly alter species survival and composition. Slow-growing vegetation makes deserts particularly vulnerable to invasive grasses, which provide fine fuels for wildfire; ultimately, the cycle of invasive species and wildfire can cause type conversion to grasslands. Non-climate stressors (e.g., invasive species) have already disturbed and/or fragmented many desert habitats.

Adaptive Capacity	<u>Habitat extent, integrity, and continuity</u>: Low-moderate geographic extent, low-moderate integrity (partially degraded), moderate continuity

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[1] Confidence: High

Resistance and recovery: Low resistance and recovery potential
Habitat diversity: Moderate-high overall diversity
Management potential: Low societal value, low-moderate management potential

Although desert habitats remain less fragmented than many other habitats in the state, factors such as land-use conversion, agriculture, and energy production and mining have created significant landscape barriers in some areas. In general, desert environments are slow to recover from disturbance, in part because species exist close to their physiological limits. However, many species have developed adaptive traits to minimize water loss and resist adverse impacts from high air and soil temperatures. Because of this, desert species may be able to expand their ranges where barriers do not limit habitat migration. Due in part to extreme climatic conditions, desert habitats harbor an extraordinary amount of biodiversity, including many rare, endemic, and threatened/endangered species; however, the value of desert habitats can sometimes be overshadowed by their perceived value for energy and agricultural development.

Sensitivity

The overall sensitivity of desert habitats to climate and non-climate stressors was evaluated to be moderate by habitat experts.[2]

Sensitivity to climate and climate-driven changes
Habitat experts evaluated desert habitats to have moderate-high sensitivity to climate and climate-driven changes,[3] including: precipitation, soil moisture, low stream flows, drought, and extreme heat events.[4]

The same harsh conditions driving speciation and the resulting high levels of biodiversity in desert habitats cause many species to persist close to their physiological thermal and water stress thresholds (Archer and Predick 2008). These factors limit their geographic distribution and make them vulnerable to extirpation or extinction as connectivity to physiological refugia declines or disappears in the face of changing climatic conditions.

Precipitation, groundwater levels, and soil moisture
Annual precipitation can be as low as 125 mm (5 in) in southern California deserts, and rain falls primarily during the winter, although summer monsoons occasionally reach the eastern Mojave Desert and western Sonoran Desert (Archer and Predick 2008; J. Weigand, pers. comm., 2015). Consequently, desert ecosystems rely heavily on seasonal or ephemeral surface water and aquifers (Randall et al. 2010). Groundwater systems in desert basins are recharged naturally when water flows from high to low elevation in the form of precipitation and snowmelt runoff. When the storage capacity of groundwater is exceeded, flows in streams and springs surface,

[2] Confidence: High
[3] Confidence: High
[4] Factors presented are those ranked highest by habitat experts. A full list of evaluated factors can be found at the end of this document.

establishing and maintaining riparian systems that provide ~75% of desert animal species with essential habitat (Randall et al. 2010). In many areas, aquifers are increasingly depleted by unsustainable groundwater pumping for human use (Randall et al. 2010).

Desert habitats are water-limited systems, and as such the vegetation is extremely suited to low water availability. Precipitation and soil moisture are important cues for many species' reproduction and germination, and timing of precipitation and duration of soil moisture availability can determine species survival (C. Barrows, pers. comm., 2015). This is particularly true for Sonoran Desert plant species that have adapted to biannual summer and winter precipitation peaks (Archer and Predick 2008; C. Barrows, pers. comm., 2015). During years of above average rainfall, invasive plants often gain a competitive advantage, increasing herbaceous cover (Germano et al. 2012) and fine fuel continuity (Archer and Predick 2008). This increases the possibility of wildfire (which was previously uncommon) and may result in vegetation type conversion to non-native annual desert grassland (Archer and Predick 2008).

Palm Oases: A unique desert resource

Palm oases are very important resources within desert ecosystems, and can be found in the southern Mojave and western Sonoran Deserts, principally along earthquake faults. Palm oases are comprised primarily of phreatophytic species, which require that their roots are always in contact with a stable water source, whether aboveground seeps and springs or in areas where groundwater is close to the surface (M. Murphy-Mariscol, pers. comm., 2015). Oases act as refugia for desert species, providing vegetative cover, shade, and water (Laudenslayer 1988). The California fan palm (*Washingtonia filifera*) characterizes these habitats and requires very wet winters for reproduction (Laudenslayer 1988). This species has an estimated life span of approximately 150 years, and oases can sustain themselves by reproducing only once per century during wet winters with the conditions needed for germination and seedling survival (Vogl and McHargue 1966). Dependence on a stable water source makes palm oases particularly sensitive to changes in precipitation and groundwater availability.

Drought

Many Sonoran plant seedlings may not become established under longer periods of drought, reducing plant recruitment and shifting the vegetation community age structure toward older age classes (C. Barrows, pers. comm., 2015). However, drought typically decreases invasive grass cover (Germano et al. 2012). While this could decrease fine fuel available for wildfire (Vulnerability Assessment Reviewers, pers. comm., 2015), large amounts of dry biomass become available within the understory of palm oases and wildfire can be carried downslope from neighboring habitats (J. Weigand, pers. comm., 2015).

Drought may also exacerbate the effects of disease on wildlife. For instance, distemper outbreaks have been associated with drought conditions in African lions (Munson et al. 2008), suggesting that drought may cause shifts in the level and type of pathogen exposure. This may lead to the convergence of multiple diseases, killing high numbers of animals already weakened by food and water stress (Munson et al. 2008). Desert kit foxes (*Vulpes macrotis*) are particularly sensitive to diseases such as rabies and distemper, which can cause significant population declines (Cypher 2003).

Air temperature and extreme heat events

Temperatures in the Mojave and Sonoran deserts can range from winter lows of 0°F in high-elevation sites to summer highs of 130°F in Death Valley (Randall et al. 2010). Desert vegetation is, overall, less sensitive to high temperatures than most other vegetation types (Levitt 1980). For example, acclimation to high temperatures can occur in some desert species, enabling them to survive extremes without great injury (Levitt 1980). However, heat stress can damage the ability of plants to photosynthesize, perhaps by affecting photosynthetic membranes or other physical structures within a leaf (Seemann et al. 1984), or by changing the chemical reactions that take place during the process (Levitt 1980). Rising temperatures can also stress plants indirectly by increasing evapotranspiration, causing an associated loss of soil moisture (Levitt 1980).

Desert wildlife species depend upon thermal refugia for survival, which can occur in narrow canyons with tall walls, on north- and northeast-facing slopes, in riparian areas, and underground (J. Weigand, pers. comm., 2015). Lizards and other reptiles are particularly sensitive to temperature changes because they are unable to moderate their own body heat. In addition, when temperatures are extremely high, many reptile species that must already seek shade for most of the day are forced to limit their foraging activities even further. The combination of heat stress and foraging restrictions can cause declines in growth, survival, and reproduction, and many local reptile extirpations have already occurred as temperature thresholds were overtaken (Sinervo et al. 2010).

Low stream flows

Most streams in southern California deserts are intermittent or ephemeral, constituting desert washes. Water flow may occur belowground even though water is not present on the surface. The Mojave River is one of the largest ephemeral rivers in the California deserts, and its confinement by the Mojave Forks Dam serves as flow control for Lucerne Valley communities and Barstow (J. Weigand, pers. comm., 2015).

Very low streamflow leads to elevated soil salinity along riverbanks where the water has dried up and left mineral deposits behind; combined with decreased water availability, this leads to unfavorable conditions for native seedling establishment (Patten et al. 2008). In such conditions, invasion by well-adapted competitor species (such as saltcedar [*Tamarix* spp.]) can occur (Merritt and Bateman 2012). The replacement of native desert riparian species with saltcedar reduces plant species diversity and degrades the habitat value of the riparian area for wildlife species (Vandersande et al. 2001, Merritt and Bateman 2012).

Phenology

Desert ecosystems are sensitive to changes in phenology, which, in this habitat type, are driven primarily by soil moisture and secondarily by temperature (Kimball et al. 2013). Many desert plant species are ephemeral, leafing out and flowering only during the brief periods when water is available and/or at specific times of the growing season. Because of the harsh conditions and limited availability of resources in the desert, plant and wildlife species have evolved to interact closely with each other. For instance, desert tortoises (*Gopherus* spp.) range widely to seek out locally abundant sources of a few key food plants as they leaf out (Jennings and Berry 2015). The timing of blooms is also very important for many species. Flowering plants like the saguaro cactus (*Carnegiea gigantea*) depend on pollinator services from species such as migratory bats, and they offer nectar and fruit to sustain wildlife in a region with relatively few resources (Bowers 2007).

Sensitivity to disturbance regimes

Habitat experts evaluated desert habitats to have low-moderate sensitivity to disturbance regimes,[5] including wildfire and flooding.[6] Disease, insects, and wind also shape this habitat to a lesser degree (Vulnerability Assessment Reviewers, pers. comm., 2015).

<u>Wildfire</u>

Due to the infrequent nature of fire in desert ecosystems, most native vegetation is maladapted to fire, though there are some exceptions, such as manzanita (*Arctostaphylos glauca*), honey mesquite (*Prosopis glandulosa* var. *torreyana*), and California fan palm (J. Weigand and M. Murphy-Mariscal, pers. comm., 2015). For many species, fire return interval and intensity are particularly important factors (M. Murphy-Mariscal, pers. comm., 2015). For instance, mesquite resprouts vigorously after low-intensity fire, but suffers high mortality in more intense fires (CNPS 2015). Similarly, the California fan palm can tolerate limited wildfires, but high-intensity fires can leave palm oases biologically sterile for decades (C. Barrows, pers. comm., 2015).

Native desert communities recover slowly from fire, if at all, and invasive annual grasses recolonize disturbed areas more quickly than woody desert species, which grow slowly in arid environments where sun exposure is high (Randall et al. 2010). The increased presence of fine fuels can compound the departure from traditional desert fire regimes, creating a positive feedback loop as invasive species continue to move in and desert species are unable to recover (J. Weigand, pers. comm., 2015). For example, any competitive advantage the fan palm has to fire disturbance is lost when it is in direct competition for water resources with invasive species that are also fire-adapted, such as saltcedar (C. Barrows, pers. comm. 2015). However, where wildfire wipes out invasive species and local conditions do not encourage their return, wildfire frequency may decrease (Vulnerability Assessment Reviewers, pers. comm., 2015).

Desert wildlife species can also be greatly impacted by wildfire. Small mammals and reptiles may be more vulnerable than large mammals and birds, as they are less able to escape from fires. Changes in wildlife populations may occur due to high mortality in long-lived species (e.g., desert tortoise), loss of vegetative cover and food resources, and increased post-fire predation (Esque et al. 2003). For example, Ortiz and Barrows (2013) found that western yellow bats

[5] Confidence: High
[6] Factors presented are those ranked highest by habitat experts. A full list of evaluated factors can be found at the end of this document.

(*Lasiurus xanthinus*) were entirely absent in palm oases following fire (Ortiz and Barrows 2013). However, spatial heterogeneity (i.e. a matrix of burned and unburned patches across the landscape) can ameliorate the effects of wildfire, providing refugia for ground-dwelling arthropods and small mammals (Hulton VanTassel et al. 2015).

Flooding and water erosion

When water flows after a rare storm, desert soils are unable to store the rapid increase in water volume, which results in soil scouring and deposition along desert washes. Water erosion and soil deposition are part of the natural disturbance regime in desert habitats, reshaping desert geomorphology. As water carries sediment particles over the landscape, they are sorted by size as the force of the water carries smaller particles for longer distances. Additionally, soluble minerals (salts) form crusts as stormwater evaporates, creating soil structure and driving the distribution of species sensitive to soil salinity (J. Weigand, pers. comm., 2015).

Flood events can serve as beneficial drivers for dispersal and propagation of woody riparian species such as honey mesquite, Fremont's cottonwood (*Populus fremontii*), and Goodding's willow (*Salix gooddingii*), and these species outperform their invasive competitor, saltcedar, in flood conditions (Vandersande et al. 2001). However, the timing and intensity of flood events can cause differential impacts on native species (M. Murphy-Mariscal, pers. comm., 2015). For example, a shift towards summertime precipitation and flood events would be detrimental to species that are adapted to winter/spring precipitation events for recruitment.

Wind erosion and soil loss/deposition

Soil loss and deposition from wind erosion also play a role in the desert disturbance regime. Where fragmentation of soil surfaces occurs, the physical (salt or clay) or biotic soil crust is disrupted and underlying soil particles or sediments are exposed to wind. Increased storm intensity, soil desiccation, wildfire, and loss of the biotic crust can lead to further soil loss (J. Weigand, pers. comm., 2015). Disturbances such as these can also alter the microbiotic species composition in desert soils, which are determined, in part, by wet-dry cycles that alter microbial respiration (Archer and Predick 2008). Changes in microbial composition can reduce net primary productivity, soil nutrient cycling, and soil carbon sequestration (Archer and Predick 2008).

Desert ecosystems lack extensive vegetation to disrupt wind, so wind speeds are often high and aerosolization of soils is widespread. Loamy soils (i.e. soils that are high in silt-sized particles) and gypsum-rich soils, which lack vegetative cover, are particularly prone to wind erosion. Aerosolized soils serve as a major vector for Valley fever spores (*Coccidioides* spp.), a fungal pathogen afflicting residents of the San Joaquin and Central Valleys of California (Brown et al. 2013). Valley fever epidemics in the San Joaquin Valley are linked to droughts and increased dust from human disturbance (e.g., farming and construction; J. Weigand, pers. comm., 2015).

Wind disturbance can also have positive effects on desert ecosystems by piling sand into hummocks and nourishing dune habitats. These protected areas create habitat for dune-adapted species and thermal refugia for wildlife (Vulnerability Assessment Reviewers, pers. comm., 2015).

Sensitivity and current exposure to non-climate stressors

Habitat experts evaluated desert habitats to have high sensitivity to non-climate stressors,[7] with an overall low-moderate exposure to these stressors within the study region.[8] Key non-climate stressors identified for desert habitats include invasive and other problematic species.[9] Some habitat experts also identified agriculture, land-use conversion, dams and water diversions, vehicular traffic, recreation, livestock grazing, transportation corridors, groundwater pumping, and energy production and mining as non-climate stressors for desert habitats.[10] The scientific literature suggests that air pollution (Allen et al. 2009) and military activities (Lovich and Bainbridge 1999; Randall et al. 2010) may also affect this habitat.

Because of dry climate, delicate soils, and the slow rate of soil crust development, plant growth, and ecological succession, desert ecosystems are particularly sensitive to anthropogenic disturbance (Randall et al. 2010). Over the past century, southern California deserts have been significantly altered by agriculture, livestock grazing, urbanization, road and utility corridor construction, pollution, mining, military training exercises, off-highway vehicle use (Lovich and Bainbridge 1999), and, more recently, renewable energy installations (Lovich and Ennen 2011). Recovery from anthropogenic disturbance and a return to pre-disturbance plant cover and biomass can vary between 50 and 300 years; complete ecosystem recovery may take over 3,000 years (Lovich and Bainbridge 1999).

<u>Invasive species</u>

Invasive species are a significant threat to desert ecosystems, especially in disturbed areas or during periods of increased precipitation (Barrows et al. 2009; Germano et al. 2012). The growth of non-native grasses is accelerated by nitrogen deposition and subsequent soil nitrification, and these grasses provide fine fuel for wildfires, which are otherwise infrequent in desert environments (Allen et al. 2009). Post-fire desert habitat may shift towards grasslands dominated by non-native grasses and forbs (e.g., Sahara mustard [*Brassica tournefortii*], bromes [*Bromus* spp.], and Mediterranean grass [*Schismus* spp.]), which can lead to significant changes in habitat structure (Barrows et al. 2009; Germano et al. 2012). For instance, in dune plots covered in Sahara mustard, native plants exhibited an 80-90% reduction in flowering and seed set (Barrows et al. 2009); plots were also more likely to be dominated by Sahara mustard in the following growing season. In plots where Sahara mustard was removed, native plant cover, flowering density, and seed set increased. This included an eight-fold increase in seedpods of endangered Coachella Valley milkvetch (*Astragalus lentiginosus coachellae*; Barrows et al. 2009).

[7] Confidence: High
[8] Confidence: High
[9] Factors presented are those ranked highest by habitat experts. A full list of evaluated factors can be found at the end of this document.
[10] Not all habitat experts agreed on these non-climate stressors.

Invasive species compete with native plants for water resources (Vulnerability Assessment Reviewers, pers. comm., 2015), and invaded areas have less open space, decreasing their suitability for many desert vertebrates such as lizards and kangaroo rats (*Dipodomys* spp.; Germano et al. 2012). Fan palm oases are also sensitive to invasive species, which includes the date palm (*Phoenix dactylifera*) in the foothills of the Coachella Valley and elsewhere (de Grenade 2013; J. Weigand, pers. obs.).

<u>Dams and water diversions</u>
Aqueducts have a negative impact on desert habitats, channelizing water and reducing the amount of time water remains in within the ecosystem. Dams also eliminate natural flow regimes, which desert vegetation relies upon for survival and seed dispersal (Vulnerability Assessment Reviewers, pers. comm., 2015). This has occurred in the Mojave Desert, where dams along the Mojave River have disrupted flow into the ecosystem (J. Weigand, pers. comm., 2015).

<u>Agriculture</u>
Conversion of desert habitats to agricultural land fragments habitat, eliminates large swaths of native vegetation, facilitates the establishment of invasive weeds, and requires large amounts of water (Randall et al. 2010; J. Weigand, pers. comm., 2015). When groundwater is used for farming, it can lower groundwater levels and alter soil salinity (Randall et al. 2010; Patten et al. 2008). However, some species benefit from the vegetative structure provided by crops, which can act as stopover and nesting habitat for migratory birds such as Swainson's Hawk (*Buteo swainsoni*). Other species, like the Northern Harrier (*Circus cyaneus*) and Short-eared Owl (*Asio flammeus*) take advantage of hunting and foraging opportunities within agricultural areas (Randall et al. 2010).

In regions where historical agricultural practices have ceased, such as in the Lucerne Valley north of San Bernardino National Forest, little native or non-native vegetation is able to colonize the large tracts of highly disturbed and structurally transformed soils (J. Weigand, pers. comm., 2015). Agricultural areas may be abandoned when water becomes unavailable or very expensive; this has occurred in the Mojave River Valley, where large areas of land have been left fallow. Overall, the impact of active agriculture on desert habitats may be diminishing, as new land conversion for agriculture is uncommon (J. Weigand, pers. comm., 2015).

<u>Livestock grazing</u>
Livestock grazing has occurred in southern California deserts for more than 150 years (Lovich and Bainbridge 1999). Because widespread grazing proliferated in the late 1800s, it is difficult to fully assess the impact of grazing due to a lack of undisturbed control sites (Lovich and Bainbridge 1999). However, some areas like the Carrizo Plain National Monument and adjacent mountains provide an approximation of natural conditions in the San Joaquin Desert (J. Weigand, pers. comm., 2015). Grazing by domestic (e.g., cattle, sheep) and wild (e.g., burro, wild horse) ungulates can negatively impact desert ecosystems by removing vegetation, altering plant species composition and structure, disturbing sensitive biological crusts and nutrient cycling in soils, compacting soil around springs and other water sources, increasing erosion, and

facilitating the establishment of non-native plants (Randall et al. 2010). In riparian areas, livestock can alter channel morphology, impact water quantity and quality, increase runoff and soil loss, and disrupt soil structure (Randall et al. 2010). Roads and other infrastructure required to maintain fences, watering troughs, and supplemental feeding stations further fragment the landscape and can amplify grazing damage in desert habitats by creating high animal densities at corrals and feeding locations (Lovich and Bainbridge 1999; Randall et al. 2010).

However, the effects of livestock grazing on desert habitats may not be entirely negative. Ostermann-Kelm et al. (2009) found that native plant diversity was higher near trails used by wild horses. Another study demonstrated that carefully managed grazing decreased the density of invasive grasses and created more open spaces, allowing local populations of blunt-nosed leopard lizards (*Gambelia sila*), San Joaquin antelope squirrels (*Ammospermophilus nelsoni*), and short-nosed kangaroo rats (*Dipodomys nitratoides brevinasus*) to increase significantly (Germano et al. 2012). This practice was especially effective in wet years when the growth of invasive species was rapid.

<u>Development (urban, energy, transportation corridors)</u>
The impacts of urban expansion and energy development include habitat loss, degradation, and fragmentation, as well as increased demands on water supply (Randall et al. 2010). In recent years, population centers in or near desert ecosystems have expanded, leading to rapid residential and commercial development. Increased infrastructure development is expected to continue in the future, and the increasing demand for water from urban centers, agriculture, and other human activities is likely to exacerbate climate-driven shifts in water supply.

In recent years, there has been an additional push to develop solar, wind, and geothermal electrical generation facilities on public land in desert ecosystems (Randall et al. 2010). Although the creation of alternatives to fossil fuels will reduce greenhouse gas emissions, both solar and wind energy facilities require large tracts of land for site placement and accompanying support infrastructure. These installations have direct impacts on wildlife survival, causing mortality from birds and bats striking reflective surfaces and wind turbines and heat-related mortality from power towers and radiant heat from reflective panels. Installations also disturb vegetation communities and soil structure and microbial life; these impacts are similar to those noted in agricultural areas (Randall et al. 2010; Hernandez et al. 2014). In addition, utility-scale energy installations in Los Angeles and San Bernardino counties have already impacted viewsheds of nearby national forests (J. Weigand, pers. comm., 2015). Randall et al. (2010) notes that, as of January 2010, permit applications for renewable energy sources (e.g., wind, solar, geothermal) covered over 4,050 km^2 of the Mojave and Sonoran Deserts. Hernandez et al (2015) found that a high percentage of installed and planned solar photovoltaic (36%) and concentrating solar power installations (48%) in California are sited in biologically rich shrubland and scrubland environments (predominately in desert regions), compared to less than 12% of solar capacity located in the built environment (e.g., roof tops and parking structures in urban areas); this indicates a preference for renewable energy development in natural areas. In addition, nearly half of those installations were less than 5 km from the nearest federally protected area.

The development of transportation corridors (e.g., roads, highways, railways) causes direct impacts to soil, vegetation, and wildlife and provides additional avenues for invasive species to establish and proliferate, in addition to fragmenting the landscape. For terrestrial vertebrates such as snakes and desert tortoises, direct mortality from high-traffic transportation corridors may have substantial effects on population-level survival rates (Hoff and Marlo 1993 cited in Randall et al. 2010).

Air pollution

In addition to direct impacts from human development, desert ecosystems near high-density population centers have higher soil nitrogen content due to the deposition of atmospheric nitrogen (Allen et al. 2009). As a result, soil nitrogen content is increasing the productivity and expansion of invasive grasses such as split grass (*Schismus barbatus*), bromes, and stork's bill (*Erodium cicutarium*).

Mining

Mining operations have been ongoing since the late 1800s; their impact on the landscape is relatively localized, with degradation occurring near pits, ore dumps, and tailings (Lovich and Bainbridge 1999). Fugitive dust and toxic tailings are generally the largest concern regarding mining, and these have implications for air quality and wildlife populations, respectively (Lovich and Bainbridge 1999).

Military activities

Historical and current military activities have also had localized impacts on desert ecosystems by fragmenting and/or degrading habitat where buildings and infrastructure are created and/or expanded, as well as where military training activities are conducted (Lovich and Bainbridge 1999; Randall et al. 2010). These impacts have resulted in the displacement and loss of species' habitats and soil degradation, compaction, and alteration (Lovich and Bainbridge 1999; Randall et al. 2010). However, some military designated areas restrict public access, providing protection from other sources of disturbance (Lovich and Bainbridge 1999).

Recreation

The increasing popularity of recreational off-highway vehicles (OHVs) in southern California desert ecosystems has impacted native plants, animals, and soils, and has led to altered runoff patterns, increased erosion, reduced species richness, and air and noise pollution (Lovich and Bainbridge 1999; Randall et al. 2010). Compaction and disturbance of soils, biological crusts, and desert pavement is significant due to their slow rate of development (up to 10,000 years), and has resulted in increases in wind and water erosion, invasive species establishment, wildfire ignition rates, and susceptibility to larger, more intense wildfires (Dregne 1983, in Lovich and Bainbridge 1999; Randall et al. 2010). Although in the Sonoran desert soil biotic crusts may be only a few millimeters thick and consist of cyanobacteria that are susceptible to disruption, those crusts may be able recover relatively rapidly (J. Weigand, pers. comm., 2015).

Lovich and Bainbridge (1999) found that species abundance and diversity of plants, small mammals, and reptiles in OHV-use areas were significantly lower than in non-OHV areas. Certain species, such as kangaroo rats, have reduced fitness due to the noise and low-frequency vibrations caused by OHVs, which may mimic or mask intra-species communication and make them less able to detect predatory cues (McGinn and Faddis 1997 cited in Randall et al. 2010; Shier et al. 2012). Trail networks for OHVs may also provide corridors for the introduction of invasive plants, in addition to further fragmenting the landscape and decreasing connectivity for wildlife (J. Weigand, pers. comm., 2015).

Future Climate Exposure

Habitat experts evaluated desert habitats to have moderate-high exposure to future climate and climate-driven changes,[11] and key climate variables to consider include: increased air temperature, changes in precipitation, decreased soil moisture, more extreme high temperature events, and increased wildfire (Table 1).[12] For an overview of projected climate changes in the region, please see the Southern California Climate Overview (http://ecoadapt.org/programs/adaptation-consultations/socal).

Seeps and springs, as well as riparian habitats, deep canyons, north/northeast-facing slopes, and higher-elevation areas may offer refugia for many species. However, as vegetative structure is lost due to wildfire or other causes, important microclimate refugia for many organisms may disappear due to lack of shade, decreased soil moisture, and increased air and soil temperatures (Randall et al. 2010).

Table 1. Anticipated desert ecosystem responses to climate and climate-driven changes.

Climate and climate-driven changes	**Anticipated desert habitat response**
Air temperature and extreme heat events *+2.5 to +9°C by 2100; heat waves, particularly humid nighttime heat events, will occur more frequently, last longer, and feature hotter temperatures*	• Loss of rare, endemic, or threatened/endangered species that persist at their physiological thermal and water stress limits • Damaged ability of plants to photosynthesize • Increased plants with CAM and C4 photosynthesis • Increased evapotranspiration and associated loss of soil moisture • Increasing dependence of wildlife on underground thermal refugia
Precipitation and soil moisture *Variable annual precipitation volume and timing; decreased soil moisture*	• Changes in plant phenology driven by precipitation and soil moisture, including earlier seed germination and blooming • Decreased seedling recruitment in California fan palms • Increased herbaceous cover during wet years (e.g.,

[11] Confidence: Moderate
[12] Factors presented are those ranked highest by habitat experts. A full list of evaluated factors can be found at the end of this document.

	invasive grasses) • Greater variability in seasonal streamflow • Greater scouring, sediment erosion, and/or streambed alterations after more intense storms
Drought *Longer, more severe droughts with drought years twice as likely to occur*	• Extended periods between aquifer recharge • Loss of critical water sources and microclimate refugia (e.g., groundwater-fed riparian areas and palm oases) • Reduced seedling establishment, leading to low plant recruitment and a shift towards older age classes • Decreased abundance of invasive grasses that act as fine fuel for wildfires • Increased abundance of drought-adapted species, including succulent plants • Increased impact of disease on wildlife
Wildfire *Increased fire size, frequency, and severity*	• Altered species composition and population structure • Delayed vegetation recovery • Increased presence of fire-adapted species (e.g., *Tamarix*) • Loss of vegetative structure and microclimate refugia for many shade-adapted or -reliant organisms • Increased invasive annual grasses and associated increases in availability of fine fuels • Temporary increase in water-repellent ground surfaces • Changes in soil microbial communities • Greater emission pulses of C, N, and Hg into the atmosphere • Direct mortality, reduced survival, and reduced reproductive success in wildlife

Hydrology, soil moisture, and drought

Reduced snowpack, earlier snowmelt runoff, and extended drought may increase the time required to recharge aquifers in the Mojave, San Joaquin, and Sonoran deserts, resulting in longer annual durations of reduced flow in groundwater systems (Randall et al. 2010; Famiglietti et al. 2011).

Predictions of monsoon activity in North America are highly uncertain because the models they are based upon are not well developed (e.g., El Niño; Bukovsky et al. 2015) and temperature differentials between the ocean and land may alter patterns of seasonal precipitation (Torres-Alavez et al. 2014). More frequent and/or more intense tropical storms originating in the eastern Pacific Ocean could alter desert stream geomorphology (e.g., widening streambeds) and riparian vegetation communities, particularly those in dry wash areas or floodplains (J. Weigand, pers. comm., 2015). For instance, tropical storms/monsoons from the Pacific Ocean produced intense storms in 1976 (Hurricane Kathleen) and 1977 (Hurricane Doreen) that affected California desert habitats, transforming the landscape around the Salton Sea (J. Weigand, pers. comm., 2015).

Wildfire
Increasing temperatures, more frequent droughts, and greater non-native grass cover are likely to increase wildfire occurrence, though desert fires are associated more strongly with dry conditions in the preceding year than with drought in the current year (Westerling and Bryant 2008). Upslope forest fires may spread more frequently to lower elevations (e.g., into the Mojave Desert from the San Bernardino National Forest; Weigand and Rodgers 2009). However, as fire-resilient vegetation alliances replace drought-stressed forests, wildfire occurrence may decrease (J. Weigand, pers. comm., 2015).

Species Distribution
Low-elevation desert communities may replace upslope vegetation because they are better suited to hot, dry conditions (Friggens et al. 2012; Kelly and Goulden 2008; Lenihan et al. 2008). Overall, desert habitat is projected to shift westward and upwards in elevation as plant species track their suitable climatic envelopes (Barrows et al. 2014; Barrows and Murphy-Mariscal 2012; Hoines et al. in press). Plant shifts in elevation have already occurred over the last century (Barrows and Murphy-Mariscal 2012; Kelly and Goulden 2008), and the distributions of desert wildlife species such as desert tortoises and chuckwallas (*Sauromalus* spp.) are expected to decline in extent, in addition to shifting upward in elevation (Barrows 2011). However, many widespread desert plant species may be limited in their ability to expand into mountainous areas because they occur in topographies and soils that are not widespread at higher elevations (e.g., bajadas, wide wash systems, saline/alkaline playas; J. Weigand, pers. comm., 2015).

Changes in phenological events, which are projected to advance earlier in the year, could also significantly affect species composition and survival (Bowers 2007; Jennings and Berry 2015; Kimball et al. 2013). Barrows et al. (2014) projects a decrease or shift in suitable habitat for 45 plant and wildlife species occurring along the Mojave-Sonoran Desert ecotone in California. Several ecologically important species, such as iconic Joshua trees (*Yucca brevifolia*), ironwood (*Olneya tesota*), and ocotillo (*Fouquieria splendens*), may experience the heaviest declines in suitable habitat (Barrows and Murphy-Mariscal 2012; Barrows et al. 2014).

Potential range extensions into southern California mountains are likely to proceed on four main fronts (see Table 2):

- Los Padres National Forest (NF): Areas adjoining San Joaquin Desert habitats in San Luis Obispo and Kern counties
- Los Padres NF/Angeles NF: Areas upslope of the Antelope Valley, Los Angeles County (Mojave Desert)
- San Bernardino NF: Areas upslope (south) of Lucerne Valley, San Bernardino County (Mojave Desert)
- San Bernardino NF/Cleveland NF: Principally San Gorgonio Wilderness, Santa Rosa and San Jacinto Mountains National Monument, the Laguna Mountains (west of Coachella Valley, Anza-Borrego Desert State Park, and BLM wildernesses in southeastern San Diego County; J. Weigand, pers. comm., 2015)

Table 2. Major California tree and shrub species with the potential to expand into National Forests within southern California mountains (J. Weigand, pers. comm., 2015).

Desert/National Forest		Mojave			San Joaquin	Sonoran	
Scientific Name	**Common Name**	ANNF	LPNF	SBNF	LPNF	CNF	SBNF
Atriplex hymenelytra	Desert holly	√	√	√			
Atriplex polycarpa	Allscale	√	√	√	√		
Encelia farinosa	Brittlebush	√	√	√	√	√	√
Encelia virginensis	Virgin River brittlebush					√	√
Justicia californica	Chuparosa					√	√
Larrea tridentate	Creosote bush	√	√	√		√	√
Lepidospartum squamatum	Scale broom	√	√	√	√	√	√
Menodora spinescens	Menodora	√		√		√	√
Parkinsonia florida	Blue palo verde					√	√
Prosopis glandulosa	Honey mesquite	√	√	√	(√)[13]	√	√
Quercus cornelius-mulleri	Muller oak	√		√		√	√
Yucca brevifolia	Joshua tree	√	√	√	√		
Yucca schidigera	Mojave yucca			√		√	√

Adaptive Capacity

The overall adaptive capacity of desert habitats was evaluated to be low-moderate by habitat experts.[14]

Habitat extent, integrity, continuity and landscape permeability

Habitat experts evaluated desert habitats to have low-moderate geographic extent (i.e. occurs in a limited area within the study region),[15] low-moderate integrity (i.e. partially degraded),[16] and moderate connectivity (i.e. connected habitat patches).[17] Habitat experts identified land-use conversion, agriculture, and energy production and mining as significant barriers to habitat continuity and dispersal.[18]

Desert ecosystems in southern California extend across the southernmost third of the state,[19] and deserts remain one of the least fragmented ecoregions in the contiguous United States (Randall et al. 2010). Development and agriculture may be the most significant anthropogenic factors affecting desert habitats (see Table 3; J. Weigand, pers. comm., 2015). The San Joaquin Desert is the smallest and most disturbed desert in southern California, primarily as a result of

[13] Non-native in San Joaquin
[14] Confidence: High
[15] Confidence: High
[16] Confidence: High
[17] Confidence: High
[18] Barriers presented are those ranked most critical by habitat experts. A full list of evaluated barriers can be found at the end of this document.
[19] Defined by the Bureau of Land Management as the California Desert District and the California Desert Conservation Area.

human activities such as agriculture, petroleum exploration and extraction, and urbanization (Germano et al. 2011), and a highly developed water delivery system has allowed agriculture to proliferate (J. Weigand, pers. comm., 2015). Imperial Valley has seen similar levels of land conversion and subsequent transformation from Sonoran Desert shrublands to irrigated farmland (J. Weigand, pers. comm., 2015).

Natural boundaries such as high-elevation slopes and coastal vegetation assemblages serve as geological barriers to the desert landscape that affect habitat extent and continuity and species dispersal (Vulnerability Assessment Reviewers, pers. comm., 2015). Anthropogenic land use can also act as a barrier; for instance, dams and diversions on the Mojave River limit the movement of fish. However, rivers and associated riparian vegetation often provide important corridors that enhance habitat connectivity.

Table 3. Location of anthropogenic barriers that affect habitat continuity and dispersal in desert habitats of southern California (J. Weigand, pers. comm., 2015).

Type of Barrier	Location
Land-use conversion	• Mojave River corridor • Coachella Valley • Central San Diego County
Energy production	• Central San Diego County (interface of Sonoran Desert) • San Gorgonio Pass
Transportation corridors	• Interstate 10 (between San Bernardino Mountains and Santa Rosa/San Jacinto Ranges)
Grazing	• San Bernardino National Forest (desert chaparral interface)
Dams and diversions	• Mojave River • Interface between the San Joaquin Desert and Los Padres National Forest

Resistance and recovery

Habitat experts evaluated desert habitats to have low resistance to climate stressors and maladaptive human responses,[20] and low recovery potential.[21] In general, desert environments are slow to recover from disturbance, and component species (both flora and fauna) exist very close to physiological limits, making them vulnerable to increasingly harsh conditions (Vulnerability Assessment Reviewers, pers. comm., 2015). Generalist shrub species will likely be the most resilient to climate change impacts, especially creosote bush (*Larrea tridentata*; Hoines et al. in press).

Desert vegetation is already adapted to survive in warm, arid habitats, and may be able to function under changing climate conditions more competitively than other species (J. Weigand, pers. comm., 2015). Advantageous traits include:

- Structural resistance to desiccation, designed to minimize excessive evapotranspiration under drought conditions by reducing stomatal conductance; common examples

[20] Confidence: High
[21] Confidence: High

include the presence of thick leaves with a low surface area-to-volume ratio, wax cuticles, and stomata sunken into pits on the leaf surface
- Alternate photosynthetic pathways better adapted to hotter and drier environments; these include C4, which efficiently sequesters carbon at high temperatures, and crassulacean acid metabolism (CAM), which enhances productivity in warmer, drier conditions
- Drought deciduousness with rapid refoliation after rains or floods
- Deep root systems that often exceed the dry biomass of aboveground vegetation
- Ability to store water within plant mass (occurs in cacti and other succulents)
- Ability to deal with poor water quality, difficult soil chemistry (e.g. salinity, alkalinity), and sporadic, intense flooding

Genetic diversity is an important component of species plasticity. Non-native plants such as saltcedar and red brome (*Bromus madritensis* ssp. *rubens*) have high levels of genetic plasticity, although wide-ranging native species such as California buckwheat (*Eriogonum fasciculatum*) and creosote bush exhibit some genetic variability as well (Laport et al. 2013; J. Weigand, pers. comm., 2015).

Habitat diversity

Habitat experts evaluated desert habitats to have moderate-high physical and topographical diversity,[22] moderate-high component species diversity,[23] and moderate-high functional group diversity.[24] Desert ecosystems harbor a large amount of biodiversity including many rare, endemic, or threatened/endangered species for which intact desert habitat is diminishing and deteriorating. Many formerly common species are now considered threatened or endangered such as the Least Bell's Vireo (*Vireo bellii pusillus*; England and Laudenslayer 1995). Additional rare, threatened, endangered, and/or endemic species include desert tortoise (*Gopherus agassizii*), Coachella Valley fringe-toed lizard (*Uma inornata*), Casey's June beetle (*Dinacoma caseyi*), arroyo toad (*Anaxyrus californicus*), Mohave ground squirrel (*Spermophilus mohavensis*), Peninsular bighorn sheep (*Ovis canadensis nelsoni*), triple-ribbed milkvetch (*Astragalus tricarinatus*), and Coachella Valley milkvetch (M. Murphy-Marical, pers. comm., 2015).

Keystone species within southern Californian desert habitats include:
- Joshua trees and Mojave yuccas (*Y. schidigera*): These species have obligate pollinators, and provide food, nesting materials, and nest and roosting sites for a variety of desert mammals, reptiles, and birds, as well as microclimate refugia for seedling establishment (M. Murphy-Mariscal, pers. comm., 2015).
- Honey mesquite: This tree is an important food source for wildlife, and hummocks at the base offer shelter and collect soil nutrients to create "islands of fertility" (Schade and Hobbie 2005).

[22] Confidence: Moderate
[23] Confidence: Moderate
[24] Confidence: High

- Ironwood (*Olneya tesota*): This tree species provides habitat for many species of insects, birds, and small mammals that depend heavily on the June seed crop, which matures when other food resources are low. They also act as nurse plants for a wide range of plant species (Hoines et al. in press; M. Murphy-Mariscal, pers. comm., 2015).
- Blue palo verde (*Parkinsonia florida*): The benefits of this species are similar to those of ironwood, but weaker bark offers excellent habitat for cavity-nesting birds, including ladder-backed woodpeckers (*Picoides scalaris*), Gila woodpeckers (*Melanerpes uropygialis*), Lucy's warblers (*Vermivora luciae*), and ash-throated flycatchers (*Myiarchus cinerascens*; McCreedy 2011; J. Weigand, pers. comm., 2015).
- California fan palm: The fruits of this species provide a food source for over-wintering wildlife, and unburned skirts provide cover for many species of birds, reptiles, and mammals, including several species of bats (e.g. western yellow bats [*Lasiurus xanthinius*]; C. Barrows, pers. comm., 2015).

Specific vegetation assemblages characterize the Mojave, San Joaquin, and Sonoran Deserts. They are principally categorized as desert shrub alliances due to the prominence of creosote bush, allscale (*Atriplex polycarpa*), brittlebush (*Encelia farinosa*), desert holly (*Atriplex hymenelytra*), white burrobush (*Ambrosia salsola*), and Joshua tree, among others (Turner 1994; see Table 4 for species that define the Mojave and Sonoran desert regions). California fan palm oases habitat can be found throughout the Sonoran Desert, but are concentrated along the Coachella segment of the San Andreas Fault (J. Weigand, pers. comm., 2015).

Table 4. Dominant plant species unique to the Mojave Desert (Turner 1994) and Sonoran Desert (Sawyer et al. 2009).

Mojave Desert		**Sonoran Desert**	
Scientific Name	Common Name	Scientific Name	Common Name
Menodora spinescens	Menodora	*Olneya tesota*	Ironwood
Cassia armata	Desert senna	*Parkinsonia florida*	Blue palo verde
Psorothamnus arborescens	Mojave dalea	*Justicia californica*	Chuparosa
Acamptopappus shockleyi	Goldenhead	*Carnegiea gigantea*[25]	Saguaro cactus

Management potential

Habitat experts evaluated desert habitats to be of low societal value.[26] Desert habitats provide many ecosystem services, including: public health, biodiversity, recreation, grazing, and carbon sequestration (Vulnerability Assessment Reviewers, pers. comm., 2015). Although they are not of high commercial value to the public, deserts are valued for their research potential and there is still much to learn about desert biotic communities and the unique adaptations of extremophile species (Vulnerability Assessment Reviewers, pers. comm., 2015). Deserts also provide opportunities for recreation, agriculture, and energy development, although these uses may have significant impacts on desert biological communities (Vulnerability Assessment Reviewers, pers. comm., 2015).

[25] This species is rare in Southern California, and does not occur near national forests.

[26] Confidence: High

Habitat experts identified that there is low-moderate potential for managing or alleviating climate impacts for desert habitats.[27] Habitat experts identified the following actions as potential management options for desert habitats: reducing nitrogen deposition, increasing carbon storage, increasing water residence time, managing non-native grasses to control wildfire frequency and severity, and reducing habitat fragmentation to allow for migration in response to changing climatic envelopes (Vulnerability Assessment Reviewers, pers. comm., 2015). Habitat experts also noted that managers in southern California mountains may wish to minimize dust emissions from activities such as farming and construction, especially in proximity to areas known to harbor Valley fever in the soils, such as the San Joaquin and Antelope Valleys (J. Weigand, pers. comm., 2015).

Habitat experts emphasized that further research and monitoring of desert biodiversity, including invertebrates and soil microbial communities, is important under changing climate conditions (J. Weigand, pers. comm., 2015). Public outreach and communication about the important ecosystem services provided by deserts should be improved to prevent continued habitat conversion (Vulnerability Assessment Reviewers, pers. comm., 2015).

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Literature Cited

Allen, E. B., Rao, L. E., Steers, R. J., Bytnerowicz, A., & Fenn, M. E. (2009). Impacts of atmospheric nitrogen deposition on vegetation and soils at Joshua Tree National Park. In R. H. Webb, L. F. Fenstermaker, J. S. Heaton, D. L. Hughson, E. V. McDonald, & D. M. Miller (Eds.), *The Mojave Desert: Ecosystem processes and sustainability* (pp. 78–100). Las Vegas, NV: University of Nevada Press.

Archer, S. R., & Predick, K. I. (2008). Climate change and ecosystems of the southwestern United States. *Rangelands*, *30*(3), 23–28.

Barrows, C. W. (2011). Sensitivity to climate change for two reptiles at the Mojave-Sonoran Desert interface. *Journal of Arid Environments*, *75*(7), 629–635. http://doi.org/10.1016/j.jaridenv.2011.01.018

Barrows, C. W., Allen, E. B., Brooks, M. L., & Allen, M. F. (2009). Effects of an invasive plant on a desert sand dune landscape. *Biological Invasions*, *11*(3), 673–686. http://doi.org/10.1007/s10530-008-9282-6

Barrows, C. W., Hoines, J., Fleming, K. D., Vamstad, M. S., Murphy-Mariscal, M., Lalumiere, K., & Harding, M. (2014). Designing a sustainable monitoring framework for assessing impacts of climate change at Joshua Tree. *Biodiversity and Conservation*, *23*, 3263–3285. http://doi.org/10.1007/s10531-014-0779-2

[27] Confidence: Moderate

Barrows, C. W., & Murphy-Mariscal, M. L. (2012). Modeling impacts of climate change on Joshua trees at their southern boundary: How scale impacts predictions. *Biological Conservation*, *152*, 29–36. http://doi.org/10.1016/j.biocon.2012.03.028

Bowers, J. E. (2007). Has climatic warming altered spring flowering date of Sonoran Desert shrubs? *The Southwestern Naturalist*, *52*(3), 347–355. http://doi.org/10.1894/0038-4909(2007)52[347:HCWASF]2.0.CO;2

Brown, J., Benedict, K., Park, B. J., & Thompson, G. R., III. (2013). Coccidioidomycosis: Epidemiology. *Clinical Epidemiology*, *5*, 185–197. http://doi.org/10.2147/CLEP.S34434

Bukovsky, M. S., Gochis, D. J., & Mearns, L. O. (2013). Towards assessing NARCCAP regional climate model credibility for the North American monsoon: Current climate simulations. *Journal of Climate*, *26*(22), 8802–8826. http://doi.org/10.1175/JCLI-D-12-00538.1

CNPS. (2015). A manual of California vegetation, online edition. Retrieved April 8, 2015, from http://www.cnps.org/cnps/vegetation/

Cypher, B. L. (2003). Foxes (Vulpes species, Urocyon species, and Alopex lagopus). In G. A. Feldhamer, B. C. Thompson, & J. A. Chapman (Eds.), *Wild mammals of North America: Biology, management, and conservation* (2nd ed., pp. 511–546). Baltimore, MD: Johns Hopkins University Press.

de Grenade, R. (2013). Date palm as a keystone species in Baja California peninsula, Mexico oases. *Journal of Arid Environments*, *94*, 59–67.

England, A. S., & Laudenslayer, W. F., Jr. (1995). Birds of the California desert. In J. Latting & P. G. Rowlands (Eds.), *The California desert: An introduction to natural resources and man's impact* (pp. 337–372). Riverside, CA: Jane Latting Books.

Esque, T. C., Schwalbe, C. R., Defalco, L. A., Duncan, R. B., Hughes, T. J., & Carpenter, G. C. (2003). Effects of desert wildfires on desert tortoise (Gopherus agassizii) and other small vertebrates. *The Southwestern Naturalist*, *48*(1), 103–111. http://doi.org/10.1894/0038-4909(2003)048<0103:EODWOD>2.0.CO;2

Famiglietti, J. S., Lo, M., Ho, S. L., Bethune, J., Anderson, K. J., Syed, T. H., … Rodell, M. (2011). Satellites measure recent rates of groundwater depletion in California's Central Valley. *Geophysical Research Letters*, *38*(3), L03403. http://doi.org/10.1029/2010GL046442

Friggens, M. M., Warwell, M. V., Chambers, J. C., & Kitchen, S. G. (2012). Modeling and predicting vegetation response of western USA grasslands, shrublands, and deserts to climate change. In D. M. Finch (Ed.), *Climate change in grasslands, shrublands, and deserts of the interior American West: A review and needs assessment* (pp. 1–20). Fort Collins, CO: Gen. Tech. Rep. RMRS-GTR-285. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Germano, D. J., Rathbun, G. B., & Saslaw, L. R. (2012). Effects of grazing and invasive grasses on desert vertebrates in California. *Journal of Wildlife Management*, *76*(4), 670–682. http://doi.org/10.1002/jwmg.316

Germano, D. J., Rathbun, G. B., Saslaw, L. R., Cypher, B. L., Cypher, E. A., & Vredenburgh, L. M. (2011). The San Joaquin Desert of California: Ecologically misunderstood and overlooked. *Natural Areas Journal*, *31*(2), 138–147.

Hernandez, R. R., Hoffacker, M. K., Murphy-Mariscal, M. L., Wu, G. C., & Allen, M. F. (2015). Solar energy development impacts on land cover change and protected areas. *PNAS,* 1-6. http://www.pnas.org/content/early/2015/10/14/1517656112.full.pdf

Hernandez, R. R., Easter, S. B., Murphy-Mariscal, M. L., Maestre, F. T., Tavassoli, M., Allen, E. B., Barrows, C. W., Belnap, J., Ochoa-Hueso, R., & Allen, M. F. (2014). Environmental impacts of utility-scale solar energy. *Renewable and Sustainable Energy Reviews, 24,* 766-779.

Hoines, J., Barrows, C. W., Murphy-Mariscal, M. L., Vamstad, M., Harding, M., Fleming, K. D., & Lalumiere, K. (2015). *Assessing species' climate change risk across Joshua Tree National Park's Mojave-Colorado Deserts transition zone* (Natural Resource Technical Report NPS/XXXX/NRTR—2015 (in press)).

Hulton VanTassel, H. L., Barrows, C. W., & Anderson, K. E. (2015). Post-fire spatial heterogeneity alters ground-dwelling arthropod and small mammal community patterns in a desert landscape experiencing a novel disturbance regime. *Biological Conservation*, *182*, 117–125. http://doi.org/10.1016/j.biocon.2014.11.046

Jennings, W. B., & Berry, K. H. (2015). Desert tortoises (Gopherus agassizii) are selective herbivores that track the flowering phenology of their preferred food plants. *PLoS ONE*, *10*(1), e0116716. http://doi.org/10.1371/journal.pone.0116716

Kelly, A. E., & Goulden, M. L. (2008). Rapid shifts in plant distribution with recent climate change. *Proceedings of the National Academy of Sciences*, *105*(33), 11823–11826. http://doi.org/10.1073/pnas.0802891105

Kimball, S., Angert, A. L., Huxman, T. E., & Venable, D. L. (2010). Contemporary climate change in the Sonoran Desert favors cold-adapted species. *Global Change Biology*, *16*(5), 1555–1565. http://doi.org/10.1111/j.1365-2486.2009.02106.x

Laport, R. G., Hatem, L., Minckley, R. L., & Ramsey, J. (2013). Ecological niche modeling implicates climatic adaptation, competitive exclusion, and niche conservatism among Larrea tridentata cytotypes in North American deserts. *The Journal of the Torrey Botanical Society*, *140*(3), 349–363. http://doi.org/10.3159/TORREY-D-13-00009.1

Laudenslayer, W. F., Jr. (1988). Palm oasis. In K. E. Mayer & W. F. Laudenslayer, Jr. (Eds.), *A guide to wildlife habitats of California*. Sacramento, CA: State of California, Resources Agency, Department of Fish and Game.

Lenihan, J. M., Bachelet, D., Neilson, R. P., & Drapek, R. (2008). Response of vegetation distribution, ecosystem productivity, and fire to climate change scenarios for California. *Climatic Change*, *87*(S1), 215–230. http://doi.org/10.1007/s10584-007-9362-0

Levitt, J. (1980). *Chilling, freezing, and high temperature stresses* (2nd ed.). Oxford: Elsevier Science.

Lovich, J. E., & Bainbridge, D. (1999). Anthropogenic degradation of the southern California desert ecosystem and prospects for natural recovery and restoration. *Environmental Management*, *24*(3), 309–326.

Lovich, J. E., & Ennen, J. R. (2011). Wildlife conservation and solar energy development in the Desert Southwest, United States. *BioScience*, *61*(12), 982–992.

McCreedy, C. (2011). *Birds of Sonoran Desert xeric thorn woodlands: Patterns of bird species composition, richness, abundance, and nest survivorship, 2003-2010* (No. PRBO Contribution No. 1861). Petaluma, CA: PRBO Conservation Science.

Merritt, D. M., & Bateman, H. L. (2012). Linking stream flow and groundwater to avian habitat in a desert riparian system. *Ecological Applications*, *22*(7), 1973–1988. http://doi.org/10.1890/12-0303.1

Munson, L., Terio, K. A., Kock, R., Mlengeya, T., Roelke, M. E., Dubovi, E., … Packer, C. (2008). Climate extremes promote fatal co-infections during canine distemper epidemics in African lions. *PLoS ONE*, *3*(6), 5–10. http://doi.org/10.1371/journal.pone.0002545

Ortiz, D. D., & Barrows, C. W. (2013). *Western yellow bat (Lasiurus xanthinus) occupancy patterns in palm oases in the lower Colorado Desert*. Unpublished report on file at the BLM Palm Springs / South Coast Field Office.

Ostermann-Kelm, S. D., Atwill, E. A., Rubin, E. S., Hendrickson, L. E., & Boyce, W. M. (2009). Impacts of feral horses on a desert environment. *BMC Ecology*, *9*. http://doi.org/10.1186/1472-6785-9-22

Patten, D. T., Rouse, L., & Stromberg, J. C. (2008). Isolated spring wetlands in the Great Basin and Mojave Deserts, USA: Potential response of vegetation to groundwater withdrawal. *Environmental Management*, *41*(3), 398–413. http://doi.org/10.1007/s00267-007-9035-9

Randall, J. M., Parker, S. S., Moore, J., Cohen, B., Crane, L., Christian, B., … Morrison, S. (2010). *Mojave Desert ecoregional assessment*. San Francisco, CA: Unpublished report from The Nature Conservancy of California.

Sawyer, J. O., Keeler-Wolf, T., & Evans, J. M. (2009). *A manual of California vegetation* (2nd ed.). Sacramento, CA: California Native Plant Society Press.

Schade, J. D., & Hobbie, S. E. (2005). Spatial and temporal variation in islands of fertility in the Sonoran Desert. *Biogeochemistry*, *73*(3), 541–553. http://doi.org/10.1007/s10533-004-1718-1

Seemann, J. R., Berry, J. A., & Downton, W. J. S. (1984). Photosynthetic response and adaptation to high temperature in desert plants: A comparison of gas exchange and fluorescence methods for studies of thermal tolerance. *Plant Physiology*, *75*(2), 364–368.

Shier, D. M., Lea, A. J., & Owen, M. A. (2012). Beyond masking: Endangered Stephen's kangaroo rats respond to traffic noise with foot drumming. *Biological Conservation*, *150*(1), 53–58.

Sinervo, B., Méndez-de-la-Cruz, F., Miles, D. B., Heulin, B., Bastiaans, E., Villagrán-Santa Cruz, M., … Sites, J. W., Jr. (2010). Erosion of lizard diversity by climate change and altered thermal niches. *Science*, *328*, 894–899. http://doi.org/10.1126/science.1184695

Torres-Alavez, A., Cavazos, T., & Turrent, C. (2014). Land-sea thermal contrast and intensity of the North American monsoon under climate change conditions. *Journal of Climate*, *27*(12), 4566–4580. http://doi.org/10.1175/JCLI-D-13-00557.1

Turner, R. M., & Brown, D. E. (1994). Sonoran Desert scrub. In D. E. Brown (Ed.), *Biotic Communities: Southwestern United States and Northwestern Mexico* (pp. 181–221). Salt Lake City, UT: University of Utah Press.

USDA Forest Service. (2013). *Final Supplemental Environmental Impact Statement: Southern California National Forests Land Management Plan Amendment* (No. RS-MB-265). San Diego, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Region.

Vandersande, M. W., Glenn, E. P., & Walworth, J. L. (2001). Tolerance of five riparian plants from the lower Colorado River to salinity drought and inundation. *Journal of Arid Environments*, *49*(1), 147–159. http://doi.org/10.1006/jare.2001.0839

Vogl, R. J., & McHargue, L. T. (1966). Vegetation of California fan palm oases on the San Andreas Fault. *Ecology*, *47*(4), 532–540. http://doi.org/10.2307/1933929

Weigand, J., & Rodgers, J. (2009). Active restoration in the Mojave Desert. In R. H. Webb, L. F. Fenstermaker, J. S. Heaton, D. L. Hughson, E. V. McDonald, & D. M. Miller (Eds.), *The Mojave Desert: Ecosystem processes and sustainability* (pp. 378–409). Reno, NV: University of Nevada Press.

Westerling, A. L., & Bryant, B. P. (2008). Climate change and wildfire in California. *Climatic Change*, *87*(1), 231–249.