U.S. FISH & WILDLIFE SERVICE

Joshua Tree Species Status Assessment

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1.0 EXECUTIVE SUMMARY

This Species Status Assessment (SSA) provides an analysis of the overall species viability for two species of Joshua tree, *Yucca brevifolia* and *Yucca jaegeriana*. To assess the viability of each species, we, the U.S. Fish and Wildlife Service (Service), used the conservation biology principles of resiliency, redundancy, and representation (Figure ES-1) (3 R's). Specifically, we identified the species' ecological requirements and resources needed for individual survival and reproduction. We described the stressors (threats) influencing these resources and evaluated current levels of population resiliency and species redundancy and representation using available metrics to forecast the ability of each species to sustain populations into the future.

Joshua trees are distinctive evergreen, xerophytic monocots iconic to the Mojave Desert. Both species occur on alluvial fans, plains, and bajadas in U.S. southwestern deserts in four states. They are distributed across large climate and vegetation gradients in three deserts, the Mojave, Great Basin, and Sonoran. To survive and reproduce, individuals of each species need alluvial soils, precipitation during key stages of their life cycle (both summer and winter), appropriate temperature regimes, rodents to disperse and cache seeds, nurse plants to enhance seedling survival, and pollination by an obligate yucca moth unique to each species. Resilient Joshua tree populations require multiple stable or increasing connected local populations distributed across the range in a variety of ecological settings to persist.

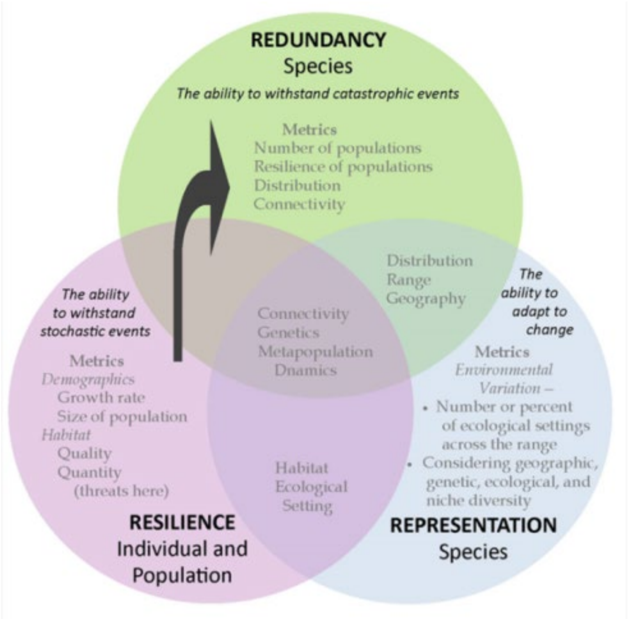


Figure ES-1: Venn diagram depicting the principles and definitions of population resilience and species redundancy and representation.

Data on Joshua tree recruitment, survival, and abundance trends across the range of each species are lacking, but population dynamics are typical of other perennial desert plant species characterized by infrequent germination, slow growth, and long life spans. Because rangewide demographic data is lacking, we used habitat variables to assist us in assessing the current population resiliency for the two species. *Yucca brevifolia* currently occurs in two regional populations across 5 million acres of habitat supporting resource needs in the western Mojave and southern Great Basin Deserts. *Yucca jaegeriana* currently occurs in three regional populations across 6.3 million acres of habitat supporting resource needs in the eastern Mojave, southern Great Basin, and western Sonoran Deserts. We also identified a Hybrid Zone (131,107 acres) to designate the area where both species occur together on the landscape, along with their obligate pollinating moths, and where hybrid trees occur. Threats such as wildfire, increasing temperatures (both minimum and maximum), drought, and habitat loss may affect the resiliency of each species. Available data indicate these threats can lead to individual mortality, especially to small-size plants less than 25 centimeters (10 inches) tall. However, these threats to individual trees are not likely influencing population resiliency on a population or species scale since there is no evidence to indicate any recent population size reductions or range contractions and limited demographic studies indicate recruitment is occurring.

We evaluated species redundancy based on the ability of both Joshua tree species to withstand catastrophic events. There are currently five regional populations widely distributed throughout the Mojave, southern Great Basin, and western Sonoran Deserts. Because of the large distribution, catastrophic risk is spread across very large areas of more than 1 million acres per population. Additionally, a high percentage of these areas is owned or managed by Federal agencies (Table ES-1), so urban development that could lead to fragmentation and loss of connectivity is limited. Moreover, each species has over 1 million acres under Federal management or conservation designations, which generally limit large-scale habitat disturbances and provide more intact ecosystems that may support more resilient local populations of Joshua trees.

Table ES-1: Habitat acres supporting *Yucca brevifolia* and *Y. jaegeriana* populations and percent of Federal ownership

Regional Populations	Area Supporting Resource Needs (Acres)	Percent Federal
Yucca brevifolia South	3,661,960	47
Yucca brevifolia North	1,977,837	96
Yucca jaegeriana North	3,070,901	85
Yucca jaegeriana Central	2,069,190	96
Yucca jaegeriana East	1,282,831	67

We evaluated species representation by considering the ecological diversity of habitats both species currently inhabit. Joshua trees occur in diverse areas within their respective ranges that encompass differences in elevation, soil type, temperature ranges, rainfall amounts, and vegetation communities. This suggests both species have a high degree of flexibility to adapt to different environmental conditions, which may provide the capacity to withstand extreme environmental events, resulting in a high degree of species representation.

Currently, populations of both Joshua tree species have large distributions, ecological diversity, and a large amount of intact habitat. Therefore, we consider that Joshua tree populations now have: (1) a high capacity to withstand or recover from stochastic disturbance events (resilience); and (2) both species likely can recover from catastrophic events (redundancy) and (3) adapt to changing conditions (representation).

To assess the potential future viability of each species, we identified risk scenarios and evaluated three major threats that could affect populations on a landscape-scale level: increase in wildfire intensity and frequency (i.e., changing wildfire regime), climate change, and habitat loss. We used available data to evaluate how these threats may change and influence population resiliency and species redundancy and representation in the future. Changes to future wildfire regimes were evaluated based on a model of invasive annual grass potential and how much of the range would be more vulnerable to an altered wildfire regime. Future changes in climate (temperature and precipitation) and habitat loss were evaluated based on emission scenarios that identify trajectories in greenhouse gas emissions using certain assumptions about future demographics and economic development, technological change, energy supply and demand, and land use change. Based on the information available on potential future conditions, we selected the timeframe from the present through the end of the 21st century to evaluate Joshua tree future conditions. Though this timeframe likely incorporates only one generation of Joshua tree, predictions after that time period lose predictive capacity.

Based on the emission scenario with a higher level of impact (i.e., climate effects of increasing greenhouse emissions through the 21st century), altered fire regimes could affect up to 8.7 percent of the population distribution for *Yucca brevifolia* and 9 percent for *Y. jaegeriana*. This emissions scenario predicts average low temperature increases of 3.3–5.5°Celsius (C) and average high temperature increases of 3–6°C, which could affect large portions of the distribution for both species. Loss of habitat could affect up to 27 percent of the population distribution for *Y. brevifolia* and 13.8 percent for *Y. jaegeriana*, with most of the loss occurring in the *Y. brevifolia* south population. Combined, these threats could result in disruption or loss of individual habitat resources that could reduce seedling establishment and survival rates, reduce the possibility of range expansion or dispersal opportunities, and reduce population abundance in the future. However, because of their wide-spread distributions and adaptive capability, both species would likely continue to include a large number of individuals distributed across a regional landscape-scale area with high ecological diversity and large areas that are conserved or restricted from development. Information on how these threats would affect each species' obligate pollinator yucca moth populations in the future is not available.

Future Joshua tree viability could be influenced by low dispersal and germination rates and reduced seedling survival across both species' ranges, depending on frequency and size of wildfires and timing and intensity of increasing temperatures. However, based on available data, we conclude that at the end of the 21st century, *Yucca brevifolia* and *Y. jaegeriana* populations will continue to have the capacity to: (1) recover from stochastic events (resiliency); (2) recover, or rebound, from catastrophic events (redundancy); and (3) adapt to changing environmental conditions (representation).

2.0 INTRODUCTION

The Joshua tree (*Yucca brevifolia/jaegeriana*) occurs in desert regions in the southwestern U.S. On September 29, 2015, we received a petition from Taylor Jones (representing Wild Earth Guardians), requesting that *Y. brevifolia* – either as a full species (*Y. brevifolia*) or as two infraspecific taxa (*Y. brevifolia* var. *brevifolia*, *Y. brevifolia* var. *jaegeriana)* – be listed as threatened and, if applicable, critical habitat be designated under the Endangered Species Act of

1973, as amended (16 U.S.C. 1531 *et seq.*) (Act). This Species Status Assessment (SSA) is intended to be an in-depth review of the species' biology, resources needed to maintain population resilience, current condition and factors threatening that condition, and potential future conditions and how those may affect long-term viability.

3.0 SSA METHODOLOGY

This document draws scientific information from resources such as primary peer-reviewed literature, reports submitted to the Service and other public agencies, species occurrence information in GIS databases, and expert experience and observations. It is preceded by, and draws upon analyses presented in, other Service documents including the 90-day finding (84 FR 63160). Finally, we coordinated with our Federal, State, and Tribal partners, and engaged with researchers conducting ongoing research efforts. We consider the information we obtained to be the most current scientific and commercial conservation status information available for the species. In the future, should additional information become available and the need arise, we will revise this document to reflect the most current information available on the status of the two species.

Analytical Framework

The SSA analytical framework is designed for assessing a species' current biological condition and its projected capability of persisting into the future (Smith *et al.* 2018, entire). Building on the best of our current analytical processes and the latest scientific information in conservation biology, this framework integrates analyses that are common to all functions of the Act (i.e., Listing, Recovery, Consultation), eliminates duplicative and costly processes, and allows us to strategically focus on our core mission of conserving, protecting, and enhancing fish, wildlife, and plant resources. The document is temporally structured, generally walking the reader through what is known from past data, how data inform current species' status, and what potential changes to this status may occur in the future based on data and models. The future condition analysis includes the potential conditions that the species or its habitat may face and discusses probable scenarios if those conditions come to fruition. The scenarios include consideration of the sources most likely to impact the species at the population or rangewide scales in the future, including potential synergistic effects.

For the purpose of this assessment, we generally define species persistence as the ability of the species to sustain populations in the natural ecosystem beyond a biologically meaningful timeframe. Joshua tree is a long-lived species, having a generation time of 50 to 70 years (Esque *et al.* 2015, p. 89), so a biologically meaningful timeframe to observe effects to the species, such as population growth trends, population extirpation, and habitat colonization events may take centuries. We are unable to forecast species persistence to that long of a timeframe. We will use timeframes for future model forecasts that are available for stressors identified in this assessment. These forecasts include some unknown level of uncertainty.

Using the SSA framework (Figure 1), we consider what the species needs to maintain viability by characterizing the status of the species in terms of resiliency, redundancy, and representation (Shaffer and Stein 2000, pp. 301-302; Wolf *et al.* 2015, entire).

We begin the SSA with an understanding of the species' unique life history, and from that evaluate a species' resource needs or biological requirements at the scales of individuals, populations, and species using the principles of resilience, redundancy, and representation (3 R's). In general these three concepts (or analogous ones) apply at the population and species levels, and are explained that way below for simplicity and clarity as we introduce them. Throughout the rest of the document we will use "resilience" as a population-level term, and "redundancy" and "representation" as species-level terms to avoid confusion.

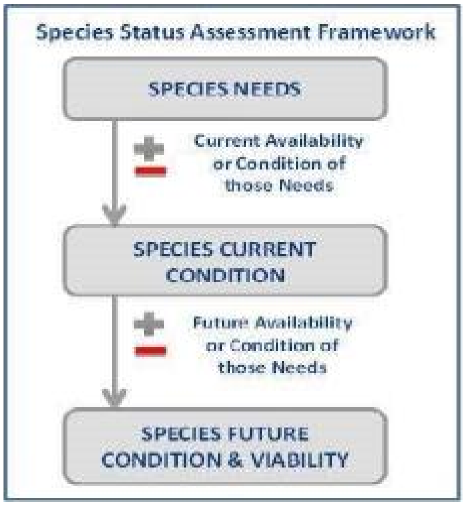


Figure 1: SSA Framework

1. Resiliency encompasses population-specific attributes that increase long-term persistence in the face of disturbance or stochastic events. It is the capacity of a population (hereafter called "population resiliency") to withstand stochastic disturbance events, that is, to rebound from relatively extreme numerical lows (individuals or populations). Species redundancy and/or representation can also be incorporated to measure population resilience.

2. Redundancy is the number of populations in a species' range. It spreads risk among multiple individuals or populations to minimize the potential loss of the population or species from catastrophic events.

3. Representation has two components, genetic and environmental. It is defined by the amount of genetic and habitat diversity among populations within the species' range. There must be enough genetic diversity remaining to avoid inbreeding depression and maintain micro (population level) or macro (species level) habitats to provide refugia during extreme environmental events. To maintain representation at either level, conservation should occur within the array of environments in which a species occurs, or within areas of significant geographic, genetic, or life history variation.

Using the SSA framework, we consider what the species needs to maintain viability by characterizing the status of the species in terms of its resiliency, redundancy, and representation.

4.0 BIOLOGICAL BACKGROUND INFORMATION

Taxonomy

Yucca brevifolia Engelm. is classified within the Clistocarpa section of the Yucca genus and was first described by George Engelmann in 1871 (Engelmann 1871, p. 496) based on a specimen collected by John Bigelow in 1854 along the banks of the Mojave River near Barstow, California (Torrey 1856, p. 147; Reveal 1977, p. 530). Since *Y. brevifolia* Engelm. was published in 1871, there have been only two validly published infraspecific taxa in *Y. brevifolia*: *Y. brevifolia* var. *jaegeriana* and *Y. brevifolia* var. *herbertii. Yucca brevifolia var. jaegeriana* McKelvey was described based on a specimen collected in the vicinity of Mountain Pass (Lenz 2007, p. 98), San Bernardino County, California (McKelvey 1938, p. 269). *Yucca brevifolia* var. *herbertii* Munz was described by Munz (1959, p. 88), based on the production of offshoots from underground rhizomes, but no taxonomic assessment has accepted *Y. brevifolia* var. *herbertii* Munz as a taxonomic entity distinct from *Y. brevifolia* (Wallace 2017, p. 3).

Research has suggested *Yucca brevifolia* var. *jaegeriana* is a distinct species. Lenz (2007, p. 100) evaluated the morphological and pollinator differences and Royer *et al.* (2016, p. 1730) evaluated the genetic structure of the two infraspecific taxa using restriction-site-associated DNA (RAD)-sequencing. These separate analyses concluded that *Y. b.* var. *jaegeriana* should be raised to specific rank (Lenz 2007, p. 97) and that it is genetically distinct from *Y. b.* var. *brevifolia* (Royer *et al.* 2016, p. 1736). Additionally, Smith *et al.* (2008b, p. 2682) concluded that *Y. brevifolia* diverged at least 5 million years ago possibly due to geographic separation by the Bouse Embayment (a Pliocene Era chain of lakes). Currently, there is a zone of overlap in the Tikaboo Valley, Nevada, where the two taxa, and their obligate moth pollinators, come into contact and plant hybridization occurs (Starr *et al.* 2012, p. 4; Royer *et al.* 2016, p. 136).

Based on the analyses in Royer (2016, entire), Smith (2008a, entire), and Lenz (2007, entire), and correspondence between the Service and editors of the Jepson Manual (Wallace 2017, p. 2) we have determined that *Yucca brevifolia* var. *brevifolia* and *Y. b.* var. *jaegeriana* are two distinct species, and we will treat them as two separate listable entities – *Y. brevifolia* and *Y. jaegeriana*, respectively. However, because both species generally have been addressed in the literature as a single species having at least two varieties or subspecies, and both have similar resource needs, we discuss them together in some sections of this assessment rather than in two separate assessments. The common name—Joshua tree—is used when the discussion of information pertains to both species.

Species Description

The Joshua tree is known as a distinctive and iconic plant of the Mojave Desert. The two species, *Yucca brevifolia* and *Y. jaegeriana*, are distinguished in the field by their respective vegetative and floral morphologies, and by their obligate yucca moth pollinator.

Yucca brevifolia is 5–12 meters (m) [16–40 feet (ft)] tall, evergreen xerophytic monocot with a somewhat spongy, indehiscent (remaining closed at maturity) fruit. The leaves are between 19–37 centimeters (cm) [7.5 and 14.6 inches (in)] long and are clustered in rosettes at the branch ends. The flowers are nearly spherical with short, wide petals that curve over the tip of the pistils and occur in dense, heavy panicles. The flowers are pollinated by *Tegeticula synthetica*, a species of yucca moth.

Yucca jaegeriana is a shorter [3–6 m (9–20 ft)] evergreen xerophytic monocot with spongy, indehiscent fruit. *Yucca jaegeriana* displays what appears to be dichotomous branching (Simpson 1975, p. 54) and has shorter leaves [less than 22 cm (8.7 in)] and shorter height to first branching at 0.75–1.0 m (2.3–3.3 ft) than *Y. brevifolia* (McKelvey 1938, p. 138; also see Figure 2, below). The flower is elongate with narrow petals that wrap around the pistil forming a corolla tube. The flower is pollinated by *Tegeticula antithetica*, a species of yucca moth. The variation in floral morphology, specifically style length, between *Y. jaegeriana* and *Y. brevifolia* is best explained by the physical characteristics of its obligate moth (Godsoe *et al*. 2008, p. 820; Yoder *et al.* 2013, p. 11), with *T. antithetica* having a shorter ovipositor than that of *T. synthetica* (see Figure 2, below) the *Y. brevifolia* pollinator.

The size and growth form of Joshua trees often varies with site and climatic conditions (Simpson 1975, p. 74; Rowlands 1978, p. 12). Radial and vertical growth is simultaneous (Simpson 1975, p. 20) with branching occurring only following the first flowering (McKelvey 1938, p. 130) in *Yucca brevifolia*. Following flowering, growth of the main stem in *Y. brevifolia* is replaced by axillary shoots that emerge from near the base of the inflorescence. Growth of *Y. brevifolia* becomes sympodial where the apical main stem is terminated and growth is continued by one or more lateral meristems (Simpson 1975, p. 32).The stockier, more compact form in *Y. jaegeriana* results initially from the pre-flowering dichotomous branching in young plants (Simpson 1975, p. 54). Once flowering is initiated in *Y. jaegeriana*, sympodial branching prevails (Simpson 1975, p. 56).

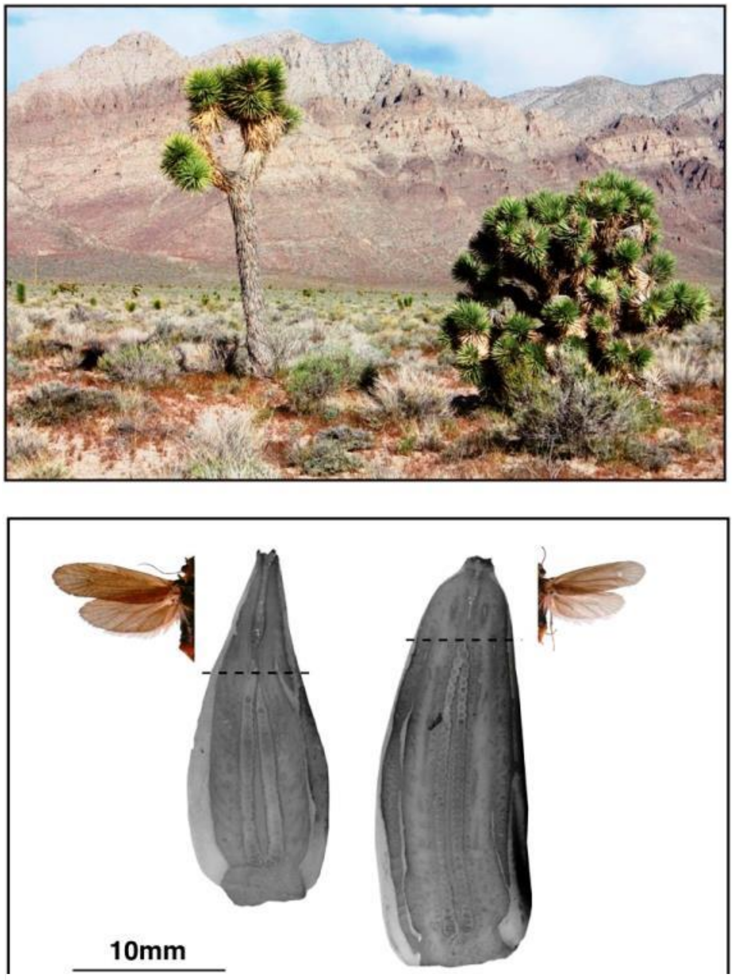


Figure 2: Top panel: *Yucca brevifolia* (left) and *Y. jaegeriana* (right) growing side by side in Tikaboo Valley, Nevada (Photo by Christopher I. Smith, used with permission). Bottom panel: Cross sections of pistils from *Y. brevifolia* (left) and *Y. jaegeriana* (right) showing differences in style length. Dotted lines indicate the lowest extent of the style. Their yucca moth pollinators (*Tegeticula synthetica* and *T. antithetica*, respectively) are shown to scale beside the styles. Adapted from Royer *et al.* 2016. Used with permission

Joshua tree leaves have thick cuticles, a waxy covering of the epidermis, thick outer walls of the epidermal cells, sunken stomata, and lack large air spaces within the mesophyll layer (just below the epidermis tissue). These leaf features appear to facilitate water conservation (Simpson 1975, p. 197). Similar to other monocots, the Joshua tree has a relatively shallow, fibrous root system which becomes more extensive in the first few weeks following germination (Simpson 1975, p. 12). An extensive root system enables more mature Joshua trees to survive long periods of drought. Another adaptation to maintain moisture is the plant's secondary tissues, which includes the outer bark. These tissues are able to conduct water and hold a quantity of water several times the plant's own weight (Simpson 1975, p. 72).

Some Joshua trees reproduce asexually through rhizomes. Rhizomes are modified underground stems capable of producing new plants, or clones, of the parent plant. Rhizomatous root production has been noted more commonly at higher elevations (Simpson 1975, p. 73). The clone is largely indistinguishable from a seedling except for subtle differences in basal root development and rhizomatous continuity with the parent plant (Rowlands 1978, p. 42).

Range and Distribution

Joshua trees have occurred in what we currently classify as southwestern deserts for at least 6 million years (Smith *et al*. 2008a, p. 255), persisting through several geologic time periods characterized by variable temperature and precipitation patterns. The last glacial maximum (ice age) occurred approximately 18,000 years-before-present (YBP) during the later stages of the Pleistocene Epoch. The Pleistocene Epoch ended about 10,000 YBP when the Laurentide Ice Sheet of North America shrank to a relatively small size (Thompson and Anderson 2017, unpaginated). Since the disappearance of this and other large ice sheets, the earth has been in an "interglacial" period of relative global warmth known as the Holocene Epoch (Thompson and Anderson 2017, unpaginated).

During the late Pleistocene, the southwestern U.S. was much wetter and cooler than it is today. For example, in the area now referred to as the Great Basin Desert, deep fresh-water lakes covered many of the now arid valleys, and the areas now classified as southwestern deserts supported plants and animals that are now restricted to higher elevations and more northerly latitudes. Climatic conditions in our southwestern deserts became warmer and drier by the middle Holocene (about 8,000 YBP), and many of the modern desert species became established within their current ranges starting around 6,000 YBP (Thompson and Anderson 2017, unpaginated). Fossil plant assemblages from packrat middens and ground sloth dung suggest that the Joshua tree had a much larger southern distribution during the late Pleistocene (between 11,000 and 30,000 YBP) that included much more of the Sonoran Desert than its contemporary distribution (Rowlands 1978, p. 120; Cole *et al*. 2011, p. 140). During this time, the climate was cooler and moister and Joshua trees occurred alongside pinyons (*Pinus monophylla*), junipers (*Juniperus osteosperma* and *J. californica*), and other plants characteristic of the Xeric Conifer Woodland vegetation type (Rowlands 1978, p. 122).

In the Sonoran Desert, the historical range may have encompassed La Paz, Maricopa, Pinal, Yuma, and Pima counties in Arizona; Imperial and Riverside counties in California; mainland Mexico; and northern Baja California, Mexico (Figure 3). The Joshua tree's historical range contracted northward along the southern edge of its range as climates warmed at the start of the Holocene (Cole *et al.* 2011, p. 141), but this contraction may have been offset by a northern range expansion (Smith *et al.* 2011, p. 10). Extinction of the North American megafauna (potential primary dispersers of Joshua tree) occurring at the beginning of the Holocene Epoch, along with Holocene climate change, has been proposed as a mechanism to explain a southern range contraction for Joshua tree (Cole *et al.* 2011, p. 148). Packrat midden analysis from Joshua Tree National Park (JTNP), California, provides a long-term record of vegetation change along the ecotone between the Sonoran and Mojave Deserts in California. One of the most notable trends in this record is the relative stability of many species within what is currently known as JTNP, including *Yucca brevifolia*, which was documented in the region about 13,880 YBP (Holmgren *et al.* 2009, p. 10).

It is difficult to determine when Joshua tree diverged into two distinct species but it was at least 5 million years ago (Smith *et al.* 2008b, p. 2682). Some researchers have speculated there was a geographical separation and isolation between 5 and 9 million years ago (Pellmyr and Segraves 2003, p. 721; Smith *et al.* 2008b, p. 2682). For this assessment, we are assuming Joshua tree in the late Pleistocene and early Holocene occurring south of its contemporary southern extent included both *Yucca brevifolia* and *Y. jaegeriana*, and that both species responded similarly to Holocene climate changes.

Contemporary Distribution

The contemporary boundary of the Joshua tree range is similar to its Holocene (~8,000 years ago) boundary but much more contracted than the Pleistocene boundary (between 22,000 and 11,700 years ago; Cole *et al*. 2011, p. 141). The current range of Joshua tree extends from northwestern Arizona to southwestern Utah west to southern Nevada and southeastern California (Figure 3). Currently, both *Yucca brevifolia* and *Y. jaegeriana* occur between 600–2200 m (1,900–7,200 ft) of elevation (Rowlands 1978, p. 51) and between 34° to 38° latitude (Rowlands 1978, p. 56) in southwestern U.S. desert ecoregions.

Because distribution mapping efforts for Joshua tree are limited, we used existing information to convey the general boundary and geographical limits of where Joshua trees occur on the landscape, as represented by polygons. The existing information comes from a number of sources, but primarily from Rowlands (1978, entire), Cole *et al.* (2003, entire and 2011, entire) and Godsoe *et al.* (2009, entire). The polygon maps were verified using Godsoe *et al*. (2009, p. 592) who mapped 5,767 presence points across the Joshua tree range. Cole's 2003 distribution mapping was updated in 2011 using presence points recorded in plots contained within the LANDFIRE Reference Database (2007, entire), the Central Mojave field data (Thomas *et al.* 2002, entire), and the Beatley Plots (Webb *et al.* 2003, entire). The Service's distribution map also incorporates a number of additional datasets (e.g., SEINet, Consortium of California Herbaria) that were combined to create the most likely distribution, or range boundary, as represented by the polygons in Figure 4 (see Appendix A for a list of all datasets and links to their associated metadata). Some areas within a polygon may no longer include Joshua trees (such as the densely urbanized areas within the cities of Palmdale, Lancaster, and Victorville, California, and Las Vegas, Nevada); however, Joshua trees do occur in the smaller, less densely developed cities like Yucca Valley in California. The Service will continue to refine the polygon boundaries as more information is received on current Joshua tree distribution.

Yucca brevifolia occurs almost exclusively in the Mojave Basin and Range ecoregion, or Mojave Desert. A small portion of its northern extent occurs within the Central Basin and Range ecoregion, or Great Basin Desert (Figure 4). It is unevenly distributed throughout southern Nevada and southeastern California. The southern extent of the range is located in the Joshua Tree National Park's little San Bernardino Mountains. The northern extent of its range is located near Alkali, Nevada. The western extent is near the Hungry Valley State Vehicular Recreation Area near Gorman, California. The eastern extent of its range is in Tikaboo Valley, Nevada, where it co-occurs with *Y. jaegeriana* (Figure 4).

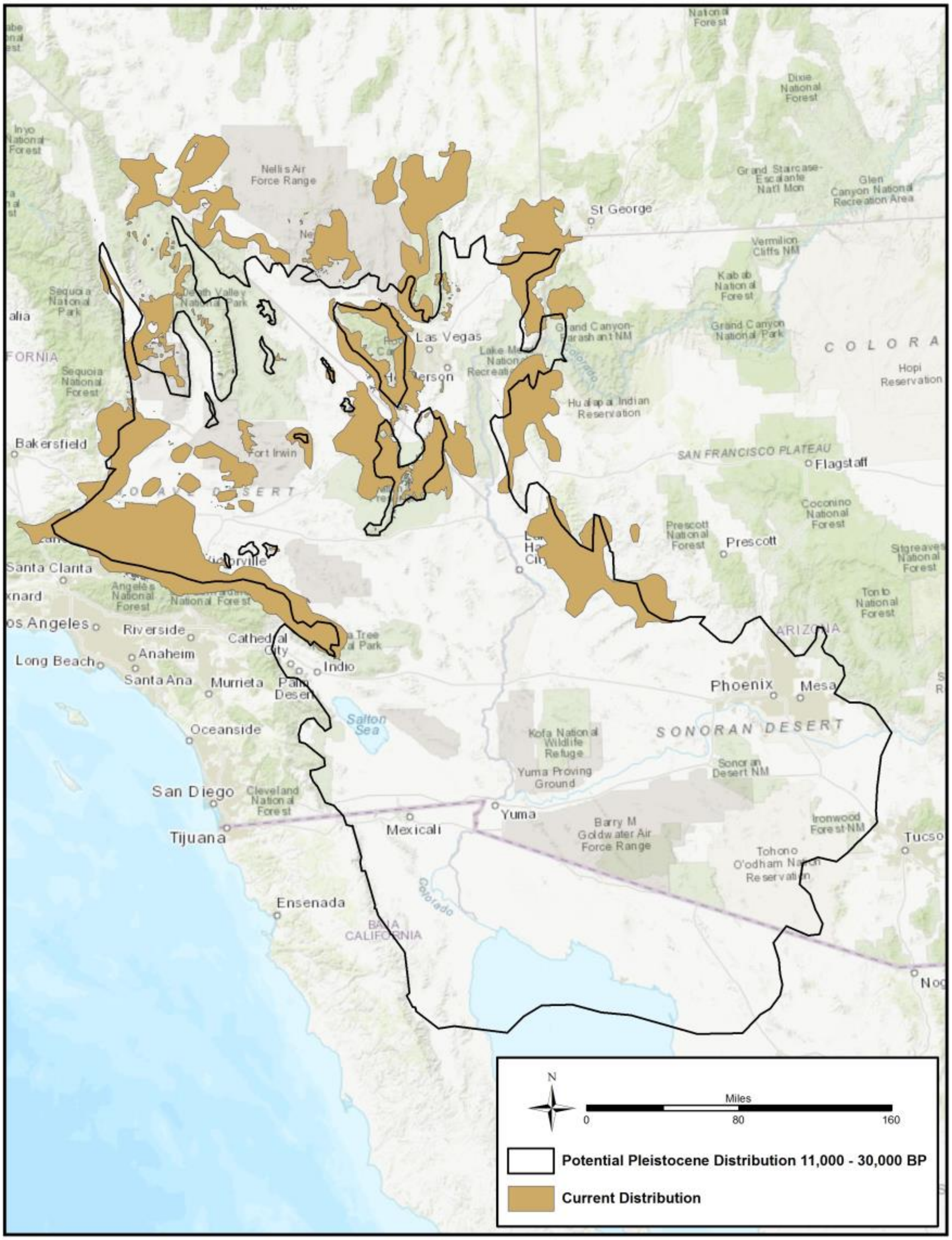


Figure 3: Joshua Tree Pleistocene Distribution. Pleistocene distribution adapted from Cole *et al*. 2011. Used with permission.

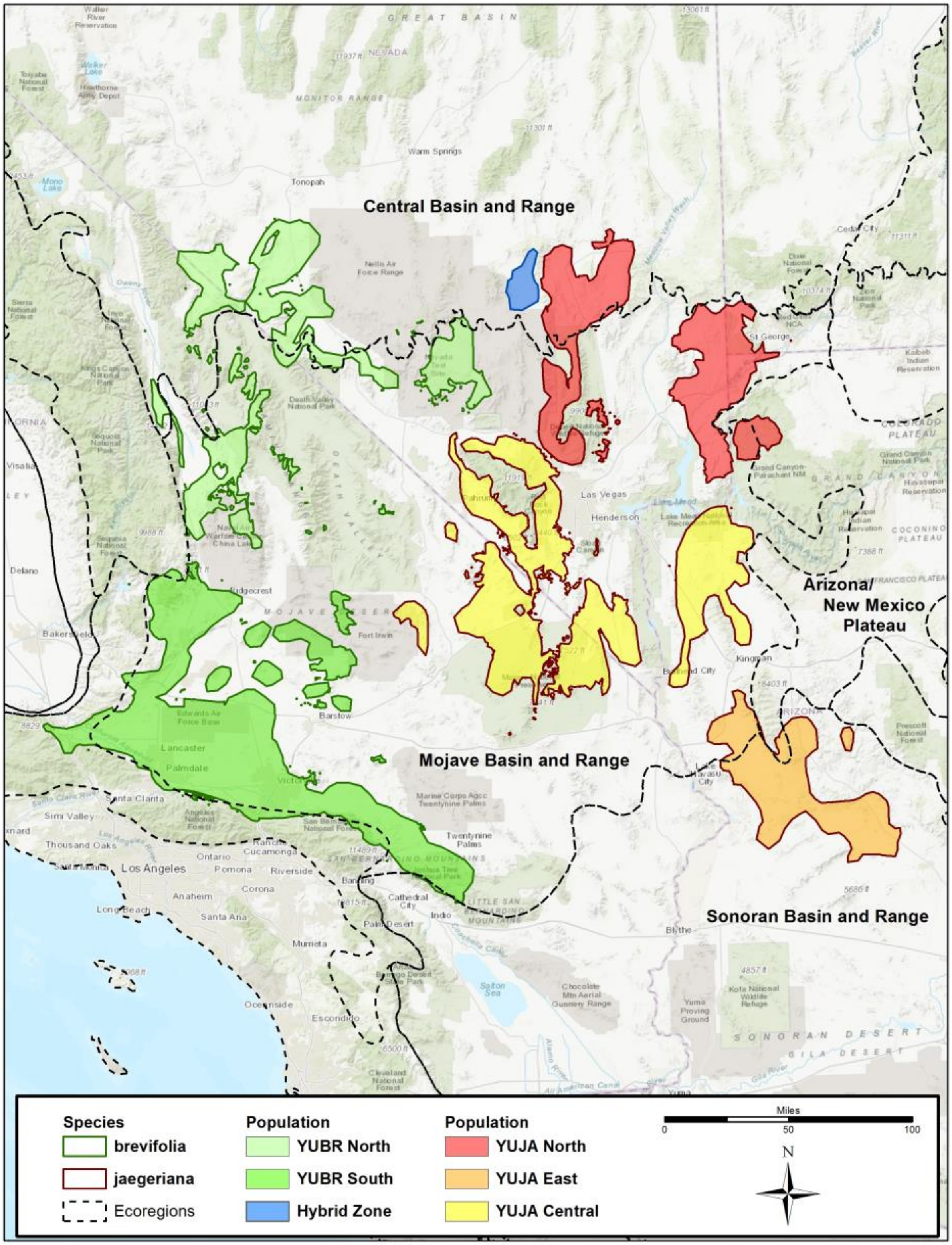


Figure 4: Joshua Tree Current Distribution. (All Maps Created by Tony Mckinney US Fish and Wildlife Service, Carlsbad Fish and Wildlife Office).

Yucca jaegeriana also occurs almost exclusively in the Mojave Desert. A small portion of its northern range falls with the Great Basin Desert and a small portion of its eastern range falls within the Sonoran Desert in Arizona (Figure 4). It is unevenly distributed throughout southeastern Nevada, southeastern California, southwestern Utah, and western and northwestern Arizona. The western limit of *Y. jaegeriana* is the Avawatz Mountains in the eastern Mojave Desert, California. The eastern and southern extent of its range is near Congress, Arizona. The northern extent is located in southern Nevada, north of Highway 93 in Dry Lake Valley. *Yucca jaegeriana* populations do not reach St. George, Utah, except as highway landscape plantings (Rowlands 1978, p. 53). In the Tikaboo Valley of southern Nevada, *Y. brevifolia* and *Y. jaegeriana* overlap and hybrids occur (see Figure 4; Starr *et al.* 2012, p. 7; Royer *et al.* 2016, p. 1731).

Approximately 78 percent of the current modeled distribution as shown in Figure 4 is owned or managed by federal or state agencies (Table 1).

Habitat

As mentioned above, Joshua trees occur almost exclusively in the Mojave Desert with portions of a few populations extending into the Great Basin Desert to the north and the Sonoran Desert to the east. Characteristic climate in these desert regions consists of long, hot summers and mild winters, with little precipitation that includes isolated thunderstorms in summer.

The Mojave Desert is classified as a warm desert ecoregion where the magnitude and seasonality of precipitation are critical drivers of ecosystem processes. Elevations in the Mojave Desert vary from 85 m (282 ft) below sea level within the Badwater Basin of Death Valley, California, to above 3,385 m (11,100 ft) in the Spring and Panamint mountain ranges in southern Nevada. Average annual precipitation is highly variable (see Figure 5). For example, based on weather station data, long-term annual precipitation varied substantially during the 20th century with a range of 34 to 310 mm/year (1.3 to 12.2 in/year; USGS 2004, p. 2). In the Mojave Desert, the amount of annual precipitation varies with elevation and to some degree with latitude (Tagestad *et al.* 2016, p. 388), and dictates vegetation composition. Seasonality of precipitation also varies from west to east with different regions experiencing different ratios of winter versus summer precipitation (USGS 2004, p. 2). The low-elevation [< 980 m (3,215 ft)] areas, which receive the least amount of annual precipitation, are currently dominated by *Larrea tridentata* (creosote bush) and *Atriplex spinifera* (saltbush). Mixed woody scrub vegetation communities are found at mid-elevations (980 to 1482 m [3,215 to 4,862 ft]) and include *Coleogyne ramosissima* (blackbrush). The high-elevation [>1482 m (4,862 ft)], most mesic regions, are dominated by *Artemisia tridentata* (sagebrush), pinyon-juniper woodland communities that include *Pinus monophylla* (single-leaf pinyon) and *Juniperus osteosperma* (Utah juniper), and interior chaparral communities that include *Adenostoma fasciculatum* (chamise), *Arctostaphylos glauca* (big berry manzanita), and *Ephedra* spp. Joshua trees are not restricted to any one desert scrub or xeric woodland community, and can be found in many different plant alliances throughout their range (Rowlands 1978, p. 54).

In the northern part of the Joshua tree range, the Mojave Desert transitions into the southern Great Basin Desert. The principal distinguishing feature of these two desert regions is the presence of creosote bush in the Mojave Desert and Sagebrush steppe in the Great Basin. The

Table 1: Population Acres, hectares, and the percentage of the species' range by major landowner (jurisdictional) categories within the range of the Joshua Tree by Population

Ownership	Acres	Hectares	Percent of Total
YUBR South			
Federal			**48%**
Bureau of Land Management	841,220	340,430	22.59%
National Park Service	214,133	86,657	5.75%
Forest Service	133,770	54,135	3.59%
Department of Defense	17,243	6,978	0.46%
U. S. Air Force	318,223	128,780	8.55%
U. S. Department of Army	127,146	51,454	3.41%
U. S. Department of the Navy	120,144	48,621	3.23%
U. S. Marine Corps	4,702	1,903	0.13%
State			
State of California	68,222	27,608	1.86%
Local			
County/City Government	928	375	0.03%
Private			
Private	1,877,460	759,781	50.41%
Subtotal	*3,724,080*	*1,507,082*	
YUBR North			
Federal			**96%**
Bureau of Land Management	1,108,288	448,508	56.04%
National Park Service	268,678	108,730	13.58%
Forest Service	4,759	1,926	0.24%
Bureau of Indian Affairs	4,935	1,997	0.25%
Department of Defense	141,678	57,335	7.16%
U.S. Department of the Navy	104,963	42,477	5.31%
Department of Energy	260,327	105,351	13.16%
State			
State of California	11,294	4,570	0.57%
State of Nevada	360	146	0.02%

Ownership	**Acres**	**Hectares**	**Percent of Total**
Local			
County/City Government	24,717	10,002	1.25%
Private			
Private	47,839	19,360	2.42%
Subtotal	*1,977,837*	*800,402*	
***Yucca brevifolia* Grand Total**	**5,701,917**	**2,307,484**	
YUJA Central			
Federal			**85%**
Bureau of Land Management	1,731,085	700,545	56.37%
National Park Service	687,981	278,416	22.40%
Forest Service	81,259	32,884	2.65%
Bureau of Indian Affairs	3,598	1,456	0.12%
Fish and Wildlife Service	19	8	0.00%
Bureau of Reclamation	3,447	1,395	0.11%
Department of Defense	1,630	660	0.05%
U. S. Department of Army	97,213	39,341	3.17%
State			
State of Arizona	26,740	10,821	0.87%
State of California	40,140	16,244	1.31%
State of Nevada	1,205	488	0.04%
Local			
County/City Government	20	8	0.00%
Private			
Private	396,565	160,484	12.9%
Subtotal	*3,070,901*	*1,242,750*	
YUJA North			
Federal			**96%**
Bureau of Land Management	1,508,783	610,583	72.9%
National Park Service	2,361	955	0.1%
Fish and Wildlife Service	350,735	141,937	17.0%
Bureau of Reclamation	5,002	2,024	0.2%
Department of Defense	110,646	44,777	5.3%

Ownership	**Acres**	**Hectares**	**Percent of Total**
State			
State of Arizona	10,003	4,048	0.48%
State of Nevada	1,312	531	0.06%
State of Utah	13,357	5,405	0.65%
Private			
Private	66,993	27,111	3.2%
Subtotal	*2,069,190*	*837,371*	
YUJA East			
Federal			**67%**
Bureau of Land Management	853,762	345,505	66.6%
Department of Defense	8,893	3,599	0.7%
State			
State of Arizona	189,875	76,840	14.80%
Private			
Private	230,301	93,199	18.0%
Subtotal	*1,282,831*	*519,143*	
***Yucca jaegeriana* Grand Total**	**6,422,923**	**2,599,265**	

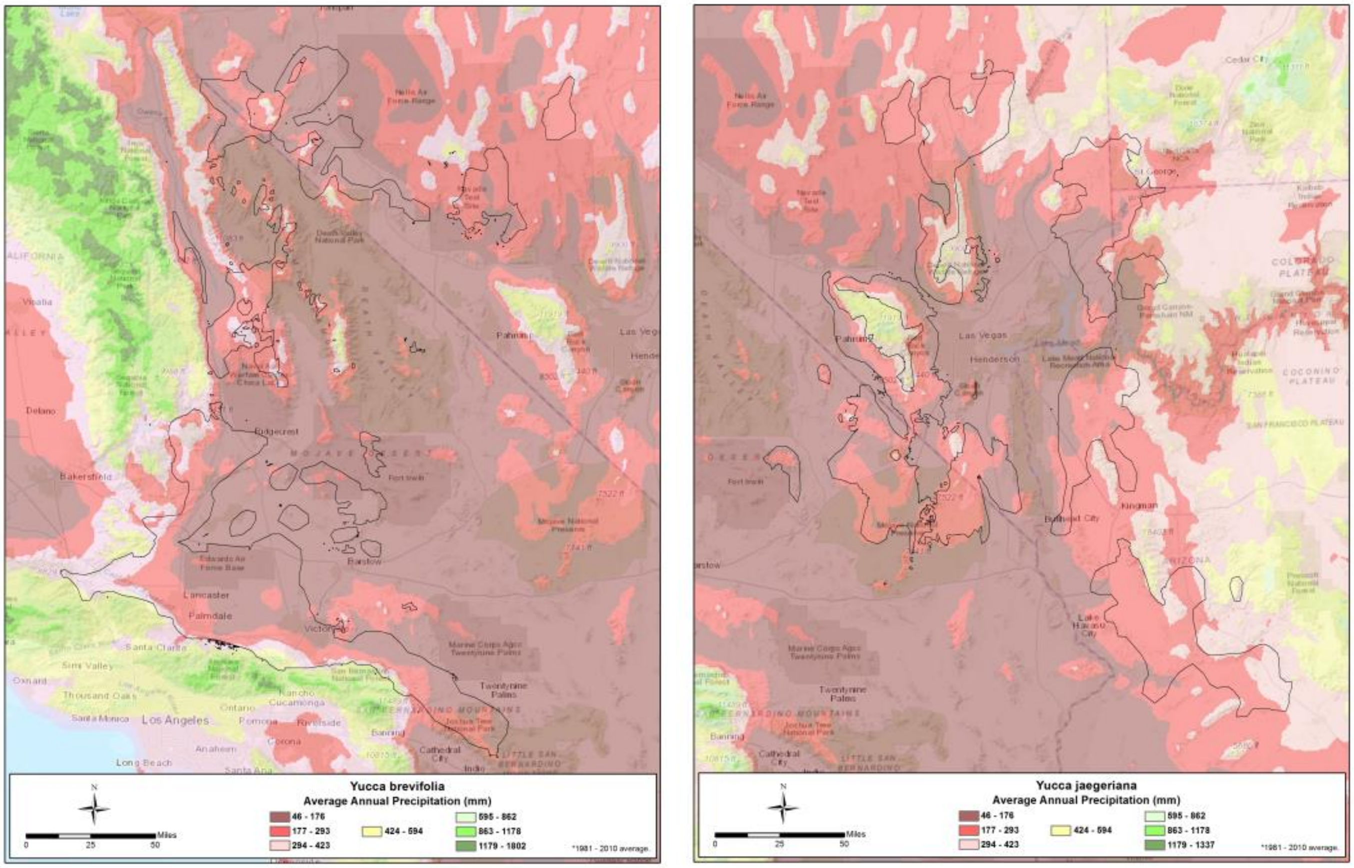


Figure 5: Average Annual Precipitation, *Yucca brevifolia* (left) and *Y. jaegeriana* (right).

Figure 6: Saline Valley in Death Valley National Park, typical density of *Yucca brevifolia* across the landscape. Photo taken December 2017 by J Wilkening, US Fish and Wildlife Service.

climate of the Great Basin is similar to the Mojave Desert region in that it is one of the most varied and extreme in terms of rainfall and temperature; however, in general, the Great Basin receives more rainfall and has cooler temperatures than the Mojave Desert.

In the southeastern part of the Joshua tree range, the Mojave Desert transitions into the Sonoran Desert. The characteristic species in the Sonoran Desert includes *Carnegiea gigantea* (saguaro), *Parkinsonia spp*. (paloverde spp.), and creosote bush. Temperatures are generally warmer and summer precipitation is higher in the Sonoran Desert than in all other parts of the Joshua tree range.

Joshua trees appear to have adapted to the varying desert climate conditions given the wide range of leaf temperature tolerances (Smith *et al*. 1983, p. 16), vegetation communities (Rowlands 1978, p. 54), and elevation and precipitation gradients as exhibited in the areas where the species is found. However, the distribution of Joshua trees does have some limitation. Joshua trees do not occur in the lowest, driest parts of the Mojave Desert, such as Death Valley and Cadiz Valley, California, and could be restricted to areas with cold winter temperatures (Went 1957, p. 178; Rundel and Gibson 1996, p. 78). Rowlands (1978, p. 179) speculated that warm season maximum temperatures and cold season minimum temperatures may limit the distribution of Joshua trees. Joshua trees are commonly associated with a variety of other plant species depending on location. Perennial grasses were usually the dominant understory vegetation in Joshua tree stands measured by Rowlands (1978, p. 173). The lower elevational limit of Joshua trees increases with latitude in response to shifting precipitation patterns and temperatures (Rowlands 1978, p. 55). Joshua trees grow poorly or die at lower elevations where other Yucca species thrive, such as *Y. schidigera* (Went 1957, p. 246).

Joshua trees are generally not the most abundant plant within a vegetation community, but some areas support high densities (Figure 6). Rowlands (1978, p. 171) suggested the “Joshua Tree Woodland” community type was not a replicable vegetation unit because Joshua tree was rarely the dominant species within the vegetation community and it could be found in a variety of vegetation communities. Based on Rowland’s (1978, p. 164) extensive surveys across the range, the “greatest size and vegetational development” of Joshua tree was found in desert grasslands or shrub communities, for example those dominated by blackbrush, creosote bush, or *Hilaria rigida* (big galleta grass).

Throughout their range Joshua trees occur on flats, mesas, bajadas and gentle slopes (alluvial fans). Joshua trees grow on a wide variety of soil types but generally on old alluvia of igneous rather than sedimentary origin, that consist of silty, loamy, or sandy soils that retain moisture (Hunning and Peterson 1973, p. 16).

Populations

Rowlands (1978, p. 72) subdivided the Joshua tree range into five regions based on differences in geographic distribution, varieties (i.e., species in this SSA), vegetation, and temperature and rainfall amounts. Based on these regions and more current distribution models (Cole *et al*. 2011, pp. 139–140), we delineated two populations of *Yucca brevifolia* [*Y. brevifolia* south (YUBR South) and *Y. brevifolia* north (YUBR North)], and three populations of *Y. jaegeriana* [*Y. jaegeriana* central (YUJA Central), *Y. jaegeriana* north (YUJA North), and *Y. jaegeriana* east (YUJA East)]. We added a sixth population, the Hybrid Zone in Tikaboo Valley, to distinguish the geographic area where both species, and their pollinators, come into contact between YUBR North and YUJA North (Figure 4).

These regional populations are each distributed over large areas [more than 1 million ac (404,686 ha)], but individual Joshua trees are not likely equally distributed and may occur in discrete patches that may not be connected to neighboring patches in terms of gene flow. Therefore, these regional populations may represent a 'regional ensemble' population structure that is a system of local populations persisting in an undefined mosaic of suitable and unsuitable habitat (Freckleton and Watkinson 2002, p. 426). Or these regional populations may represent a 'spatially extended' population with local populations existing in a patchy distribution as a consequence of disturbance and local dispersal resulting from spatially restricted dispersal patterns and population growth (Freckleton and Watkinson 2002, p. 427). Because population persistence is largely a function of processes operating at the local or regional scale (Freckleton and Watkinson 2002, p. 426), more research is needed to better inform our understanding of where local populations occur on the landscape, how the local populations interact, and how this structure influences regional population demographics to better understand Joshua tree persistence or population resiliency.

Yucca brevifolia

<u>YUBR South</u>: This *Yucca brevifolia* population falls within the area from JTNP, California, north to Ridgecrest and Red Mountain, California, mostly within the Western Mojave Basin Ecoregion. The ecoregion includes alluvial plains, fans, and bajadas of the major valleys lying between scattered mountain ranges. On the southern and western edge of the population boundary, *Y. brevifolia* trees occur within the Eastern Mojave Basins, Eastern Sierra Mojavean Slopes or Arid Montane Slope Ecoregion (Figure 7). These regions are transitional areas characterized by higher elevations and more rainfall with semi-desert montane chaparral to pinyon-California juniper woodlands. There is some variation in vegetation from north to south, but the basins typically are dominated by creosote bush and *Ambrosia dumosa* (white bursage) and the higher elevations are characterized by junipers and pinyons. Average annual rainfall varies between 82.4 mm and 738.1 mm (3.24 in and 29.06 in) and minimum temperatures range from -5.7°C (22°F) at the upper elevational limit [2200 m (7,218 ft)] to 4.8°C (41°F) at the lower elevational limit [750 m (2,461 ft)]. Mean summer high temperature are between 23.4–37.2°C (74° and 99°F) and summer precipitation is scarce (less than 10 percent of the annual total) in most areas. The range in elevations over which Joshua trees occur in this area is the greatest of any of the five regional populations (Rowlands 1978, p. 73). Associated dominant plants in stands surveyed by Rowlands (1978, p. 74) include big galleta grass, blackbrush, *Stipa speciosa* (desert needlegrass), *Oryzopsis hymenoides* (indian rice grass), creosote bush, and *Acamptopappus sphearocephalus* (goldenhead). The cities of Palmdale, Lancaster, Hesperia, Victorville, and Yucca Valley are within this population. The species occurs in varying densities throughout the low density development areas of these cities.

YUBR North: The northwest section of the range of *Yucca brevifolia* encompasses the area north of Inyokern, California, to Goldfield, Nevada, and east to and including the Nevada National Security Site (formerly Nevada Test Site). This area consists of the northern Mojave Desert, southern Great Basin Desert, and transitional vegetation types within the Tonopah Basin ecoregion (Figure 7), which is the transition between the Great Basin and the Mojave Desert. In contrast to the mostly creosote bush shrubland of the lower elevations in YUBR South, the vegetation of this higher, cooler, and wetter zone includes single-leaf pinyon, juniper, and sagebrush (Figure 7).

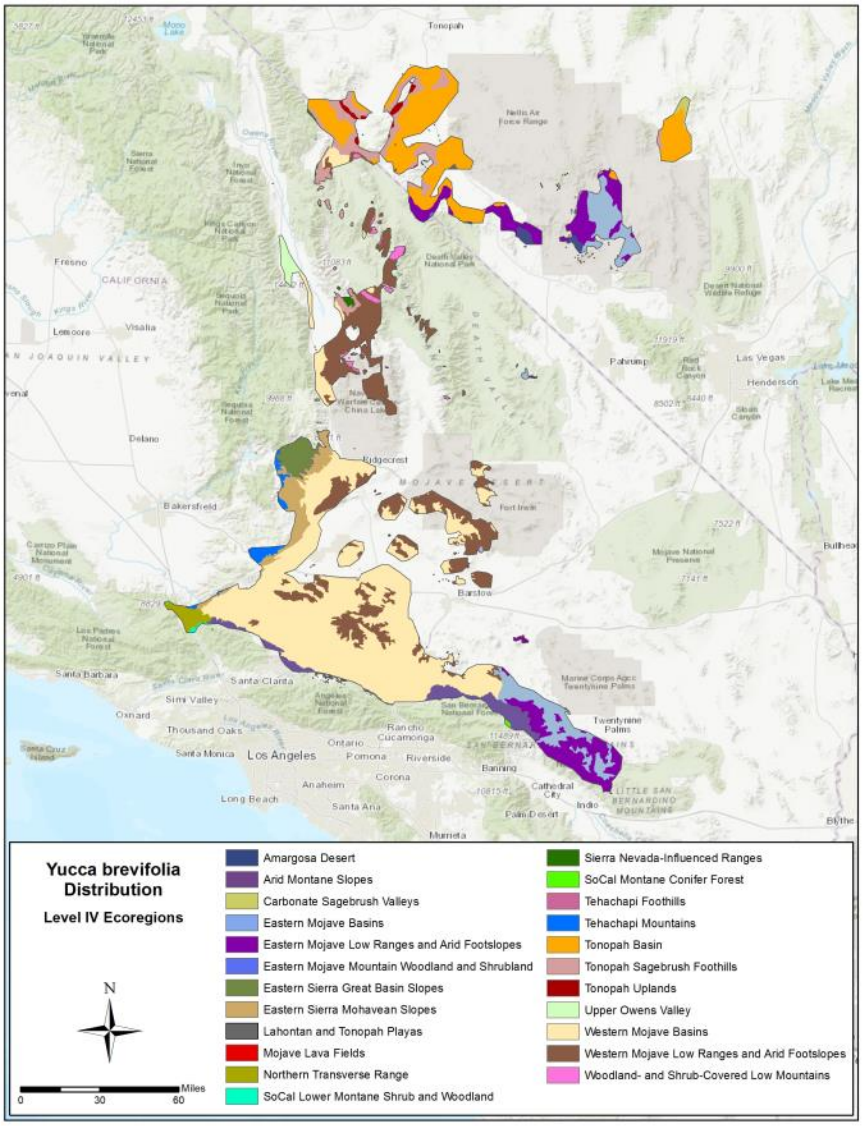


Figure 7: *Yucca brevifolia* Ecoregions

Within the Tonopah Basin, the understory includes warm season grasses, such as Indian rice grass and big galleta grass. YUBR North habitats are somewhat drier and less diverse than YUBR South. The elevation range of *Yucca brevifolia* in this population is between 1,500 and 2,200 m (4,900 and 7,200 ft). Average annual rainfall varies between 95.8 mm and 429 mm (3.77 in and 16.89 in), minimum temperatures range from -8.1–3.6°C (17–38°F), mean summer temperatures range between 20.4–36.3°C (69–97°F) and summer precipitation is 10–25 percent of the mean annual precipitation. Associated dominant plants in stands surveyed by Rowlands (1978, p. 74) include *Hilaria jamesii* (James' galleta), *Atriplex confertifolia* (shadscale), *Artemisia spinescens* (budsage), blackbrush, white bursage, and *Lycium pallidum* (wolfberry).

Figure 8: YUBR North *Yucca brevifolia* with junipers and sagebrush from Death Valley National Park. Photo taken December 2017 by J. Wilkening, US Fish and Wildlife Service.

Yucca jaegeriana

YUJA Central: This *Yucca jaegeriana* population extends east from the Avawatz Mountains in California to the vicinity of the Grand Wash Cliffs south of the Grand Canyon in Arizona, and from the vicinity of Searchlight, Nevada north to Highway 95 and Las Vegas Valley in Nevada. This population encompasses the Eastern Mojave Low Ranges and Arid Footslopes and Eastern Mojave Basins ecoregions (Figure 9). These regions are characterized by alluvial fans, bajadas, basalt flows, hills, and low mountains that rise above the basin floors. The elevation range is 900–2,000 m (2,900–6,500 ft) in most areas, but with an upper limit of less than 1,500 m (4,900 ft) in Arizona. Average annual rainfall varies between 102.3 mm and 491.6 mm (4.03 in and 19.35 in) and average minimum temperatures range from -5.3–5.9°C (22–43°F). Mean summer temperatures range from 26.9–40.3°C (80–105°F). A good proportion of the total annual precipitation falls during the summer (25–40 percent). The associated vegetation in this population is distinctly Mojavean at lower elevations but a Great Basin aspect is apparent at elevations above 1,800 m (5,900 ft). Dominant plants in this population include big galleta grass, blackbrush, Coopers goldenbush (*Ericameria cooperi*), buckhorn cholla (*Opuntia acanthocarpa*), sticky snakeweed (*Gutierrezia microcephala*), cheesebush (*Hymenoclea salsola*), Mojave yucca (*Yucca schidigera*), Nevada ephedra (*Ephedra nevadensis*), and Shockley's goldenhead (*Acamptopappus shockleyi*) (Rowlands 1978, p. 74).

<u>YUJA North</u>: This *Yucca jaegeriana* population extends from the Desert National Wildlife Refuge north to Caliente, Nevada, and east to St. George, Utah, and south to the Grand Canyon-Parashant National Monument in Arizona. This population mainly falls within the Eastern Mojave Low Ranges and Arid Footslopes and Eastern Mojave Basins ecoregions (Figure 9) within the northeastern Mojave Desert, with some areas in Nevada occurring in the Great Basin Desert, Tonopah Basin ecoregion. Many large stands of *Y. jaegeriana* can be found on the bajadas leading down from the Beaver Dam Mountains in Utah, the Delamar Mountains in Nevada, and the Grand Canyon-Parashant National Monument in Arizona. The elevational range is from 600 m (1,969 ft), in the vicinity of Littlefield, Arizona, near the Virgin River Gorge to over 2,000 m (6,561 ft) in the Delamar Mountains. Average annual rainfall varies between 109.9 mm and 441.7 mm (4.33 in and 17.39 in) and average minimum temperatures range from -6.5°C (20°F) at higher elevations, to 4.2°C (40°F) at the lower elevations. Mean summer temperatures range from 26.4–40°C, (80–104°F) with a moderate proportion of the annual average precipitation falling during the summer (20–30 percent). Associated dominant plants include creosote bush, white bursage, *Thamnosma montana* (Mojave desert-rue), sticky snakeweed, and *Krascheninnikovia lanata* (winterfat) (Rowlands 1978, p. 74).

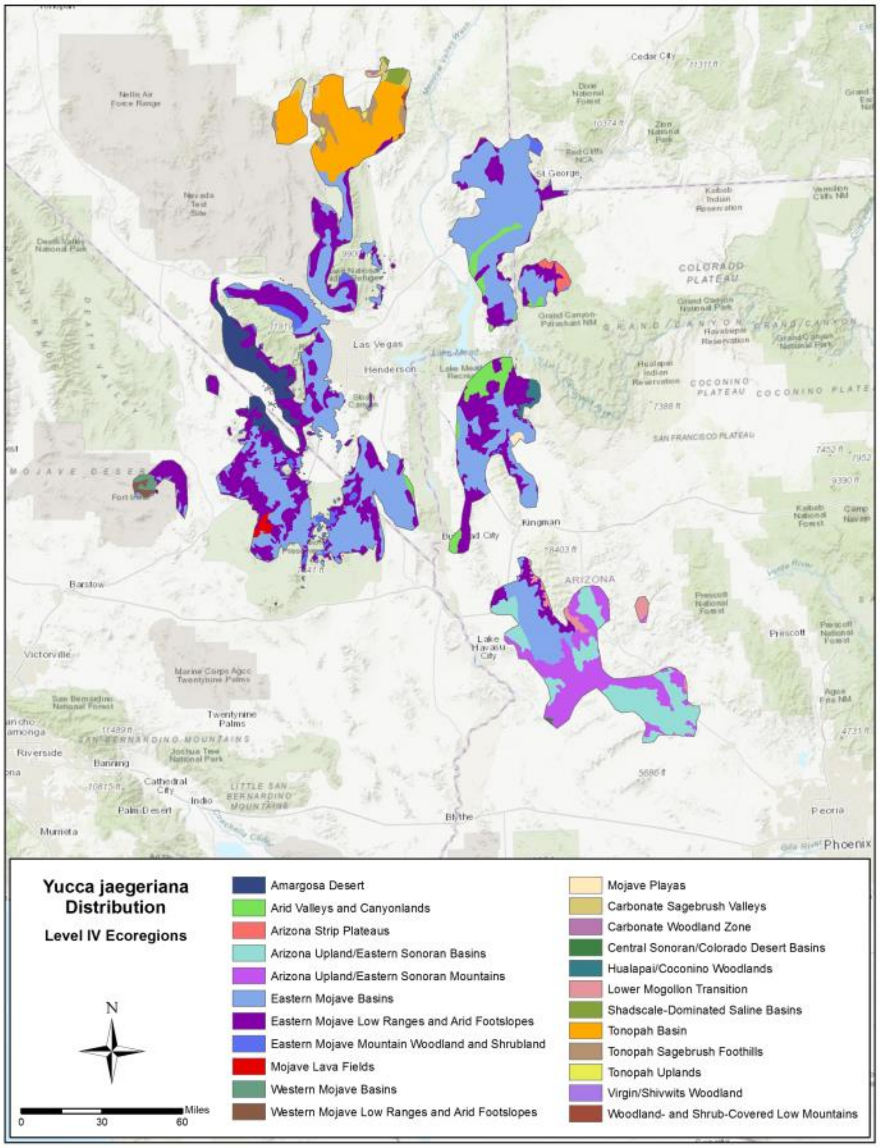


Figure 9: *Yucca jaegeriana* Ecoregions

<u>YUJA East</u>: This *Yucca jaegeriana* population in Arizona includes the area from Signal to Yucca west of the Haulapai Mountains and the area between Date Creek and the Santa Maria River. The elevation range of this population is narrow, 800 to 1,200 m (2,625 to 3,937 ft), and occurs

mostly within the Sonoran Desert. The population encompasses the Arizona Upland and Eastern Sonoran Mountains and Basins ecoregions, with some areas within the Eastern Mojave Low Ranges ecoregion (Figure 9). The Sonoran Desert ecoregions include highland areas that have more rainfall than mountain ranges farther west and have more rain in the summer. It is one of the highest and coldest parts of the Sonoran Desert. Average annual rainfall varies between 145.3 mm and 443.7 mm (5.72 in and 17.47 in) and minimum temperatures range from -1–5.5°C (30–42°F) and mean summer temperatures are between 30.8° and 40.8°C (87–105°F). A substantial portion (more than 35 percent) of the mean annual precipitation falls during the summer. The presence of saguaro (Figure 10), *Fouquieria splendens* (ocotillo), and paloverde give this population a distinctly Sonoran Desert aspect. Dominant shrubs vary widely based on location and include *Acacia greggii* (catclaw acacia), *Canotia holacantha* (crucifixion thorn), paloverde, saguaro, and California juniper (Rowlands 1978, p. 74).

Figure 10: YUJA East, Photo by James Holden, BLM Hassayampa Field Office. Photo taken September 2016, on the Forepaugh Allotment near the Harcuvar Mountains.

<u>Hybrid Zone (Tikaboo Valley)</u>: This overlap population is within the Tonopah Basin ecoregion in the Great Basin Desert of Nevada, and includes both *Yucca brevifolia* and *Y. jaegeriana*. Both species are represented in the valley along with several distinct hybrids. This population is adjacent to YUJA North to the east and YUBR North to the west. Average annual rainfall varies between 192.7 mm and 310.4 mm (7.59 in and 12.22 in) with a moderate proportion of the annual average precipitation falling during the summer (20 to 30 percent). Average minimum temperatures range from -7.2 to -2.4°C (19–28°F) and summers are warm to hot, 32–40°C, (90–104°F).

Life History and Demographics

The life history of both *Yucca brevifolia* and *Y. jaegeriana* relies on a complex set of interactions between individual plants, local vegetation communities, yucca moths, rodents, and abiotic conditions for successful reproduction and survival to become mature (sexually reproducing) adults. Joshua trees reproduce sexually through pollination and seed production and asexually by rhizome growth. Optimal reproduction and recruitment of Joshua trees requires a convergence of events, including fertilization by its obligate pollinators (Pellmyr and Segraves 2003, p. 721), seed dispersal and caching by rodents (Vander Wall *et al.* 2006, p. 543; Waitman *et al.* 2012, p. 5), seedling emergence from a short-lived seed bank triggered by isolated late-summer rainfall (Reynolds *et al.* 2012, p. 1652), and short periods of exposure to temperatures below 4° C (39° F) (Went 1957, p. 178).

Sexual Reproduction: Joshua tree sexual reproduction requires flower production, pollination, seed production, seed dispersal, and germination. Joshua trees flower between March and May throughout the range (Gucker 2006, p. 9). Once flowering occurs, which can take up to 30 years from the seedling stage (Esque *et al.* 2015, p. 89), the flowering branch stops growing and two or three branches usually develop from just below the inflorescence of the original branch (Simpson 1975, p. 44). As the new branches continue to grow, they again branch and form new branches after each successive flowering (Simpson 1975, p. 38).

Pollination is carried out through an obligate plant-pollinator mutualism – *Yucca brevifolia* and *Y. jaegeriana* flowers are pollinated by one of two moth species, *Tegeticula synthetica* or *T. antithetica,* respectively. Female moths possess maxillary tentacles, appendages unique to yucca moths that function in collecting, transporting, and transferring yucca pollen (Cole *et al*. 2017, p. 1). The interaction between the plant and the moth begins in late spring when moths fly, primarily during the day (Cole *et al.* 2017, p. 3), to inflorescences. Female moths gather a ball of pollen in their maxillary tentacles, oviposit into the yucca style, and actively transfer pollen to the stigma (Cole *et al*. 2017, p. 4). The female yucca moth oviposits in Joshua tree flowers, cutting through the ovary wall and extending her ovipositor down the stylar canal to lay eggs on the ovules (Cole *et al.* 2017, p. 4). Through this process, the female pollinates the flower, which results in the availability of seeds as a food source for larvae (Pellmyr 2003, p. 43). Yucca moth larvae hatch in the seed pod and feed on developing seeds. Other moth species will oviposit on Joshua tree flowers and larvae will hatch inside, and feed on, the seeds (Figure 11), but these are non-pollinating moths (Althoff *et al*. 2004, p. 324). In the late summer, moth larvae fall to the ground below the Joshua tree and diapause until conditions are conducive to pupation. Conditions conducive to pupation are presently unknown.

The obligate moths, *Tegeticula synthetica* and *T. antithetica*, are genetically distinct across both the nuclear and mitochondrial genomes (Smith *et al.* 2008b, p. 2680) and are parapatric (occurring in adjacent non-overlapping geographical areas) across their ranges except in a narrow contact zone in the Tikaboo Valley (Smith *et al*. 2009, p. 5220). While both pollinator species are sympatric in the Tikaboo Valley, they do not interbreed (Smith *et al.* 2009, p. 5219). Information on the abundance, distribution, survival, and population status and trend (e.g., increasing or decreasing) for these moth species is unknown. In general, Lepidopteran species are predicted to experience changes in abundance, range distribution, and in population phenology (e.g., timing of flight season, number of generations per year) with a warming climate (Kocsis and Hufnagel 2011, entire).

Figure 11: Moth larvae in Joshua tree fruit. Photo by Scott Hoffmann, Joshua Tree National Park, June 1, 2017.

Seed fertilization in *Yucca brevifolia* is the result of pollination exclusively by *Tegeticula synthetica* in all parts of the range except the Tikaboo Valley where it can also be pollinated by *T. antithetica* (Starr *et al*. 2012, p. 9). Seed production in *Y. jaegeriana* is the result of pollination exclusively *T. antithetica* since *T. synthetica* moths are unable to pollinate *Y. jaegeriana* (Starr *et al.* 2012, p. 10). Once pollinated, Joshua trees will produce fruits and seeds. Fruit and seed production likely fluctuates yearly and depends on the number of flowering individuals, availability of pollinators, and likely available moisture during fruit development. Across the range, the percent of Joshua trees flowering and producing fruit is unknown and has been characterized as irregular (Esque *et al*. 2010, p. 11), with large seed crop productions once or twice per decade (DeFalco and Esque 2014, p. 20). Seed production has also been observed as being cyclic. For example, total seed production in *Y. brevifolia* was estimated to be more than 100 times greater in 2013 than 2014 with both years of the study occurring during prolonged drought and below average rainfall (Borchert and DeFalco 2016, p. 833). The infrequent production of large crops of flowers and seeds could be an adaption to avoid seed predators or may be a response to resource accumulation, known as masting (Borchert and DeFalco 2016, p. 833). However, more research is necessary to determine if the timing and amount of precipitation or certain temperatures also influence flower and seed production in Joshua trees. When they do flower and fruit, the amount of seeds available is highly variable and can depend on fruit crop size, seeds per fruit, and pre-dispersal seed predation by moth larvae and small rodents (Waitman *et al.* 2012, p. 6; Bochert and DeFalco 2016, p. 833). Abiotic conditions that lead to high seed set are not well understood.

Seed dispersal may be carried out by ungulates or rodents. Many ungulates have been documented feeding on Joshua tree fruits, including cattle (Lenz 2001, p. 64), mule deer (Keith 1982, p. 42), and horses and burros (Lenz 2001, p. 64). However, none of these ungulates are tall enough to reach fruits in larger, older *Yucca brevifolia* trees, and to what extent they serve as *Y. jaegeriana* seed dispersers remains unknown. There are also five rodent species documented dispersing Joshua tree seeds, four species known to climb trees and three species known to be yucca seed predators (Lenz 2001, p. 65). Antelope ground squirrels and kangaroo rats cache seeds in the soil, which facilitates germination. Waitman *et al*. (2012, p. 6) found that seeds cached by rodents increased the likelihood of successful seedling emergence and that buried seeds, both in the field and laboratory, were most likely to produce emergent seedlings when buried 1–3 cm (0.4–1.2 in) deep, depths similar to the rodent caches. Seeds may also be dispersed by wind as fruits dry out and become lighter (Lenz 2001, p. 65). However, based on experiments conducted by Waitman *et al*. (2012, p. 6), wind dispersal is unlikely because fruits and seeds lack adaptations for wind dispersal and wind speeds required to move Joshua tree seeds and fruits across the soil surface were higher than those typically found in the Mojave Desert (Waitman *et al*. 2012, p. 6). Once buried, seeds have little capacity for dormancy. Based on field experiments in Piute Valley, Nevada, after 1 year in the soil, seed germination was reduced to 50–68 percent, and after 3 years germination was reduced to less than 3 percent (Reynolds *et al.* 2012, p. 1651).

Seeds germinate and emerge anytime between September through May given the right set of conditions that likely involves a combination of suitable climatic conditions, rodent activity, and desert shrub cover. Large germination and seedling emergence events do occur but are relatively rare and may occur as infrequently as twice per decade (Reynolds *et al.* 2012, p. 1652; DeFalco and Esque 2014, p. 20) or only a few times in a century (Wallace and Romney 1972, p. 191). While Joshua tree seeds appear to germinate and emerge any time after a rain, germination requires the seed to be released from the fruit, which usually occurs in summer (Went 1948, p.

250). Research conducted in Piute Valley, Nevada, found the greatest seedling emergence occurred during spring and summer, when increased soil moisture was accompanied by warm soil temperatures, indicating adaptation to regular summer rainfall (Reynolds *et al.* 2012, p. 1652). High rates of seed predation by rodents could reduce the amount of seeds available for germination (Esque *et al.* 2010, p. 11) and emergence under shrubs has been found to improve seedling emergence (Reynolds *et al.* 2012, p. 1653).

As stated above, seed germinability rates decline rapidly (within 1 year), indicating Joshua tree has little capacity for seed dormancy but seeds can germinate readily, followed by rapid growth in laboratory settings, when watered regularly and exposed to temperatures above 20ºC (68ºF) (Went 1957, p. 178). In more recent laboratory experiments, researchers found about a 95 percent germination rate (Waitman *et al.* 2012, p. 6). However, in field germination trials, germination rates ranged between about 3.2 percent (Waitman *et al.* 2012, p. 5) and 14.8 percent (Vander Wall *et al*. 2006, p. 541). These low rates likely result from a combination of granivory, drought, and rapidly diminishing seed germinability (Reynolds *et al.* 2012, p. 1652; Waitman *et al.* 2012, p. 6). These factors suggest that specific germination and establishment requirements may impose limits on seedling recruitment rates for Joshua trees.

<u>Asexual Reproduction</u>: Joshua trees can also reproduce asexually by rhizomes, branch-sprouts and/or basal-sprouts (Gucker 2006, p. 8). Most of the documented large, clonal populations occur in the higher elevation in the YUBR South population (Simpson 1975, p.73). These high elevation regions are characterized by cold temperatures, high winds, and abundant snowfall so rhizome production may be an adaptation enabling migration into more severe climatic regions (Simpson 1975, p. 437) or as a response to lack of pollinators (Rowlands 1978, p. 50).

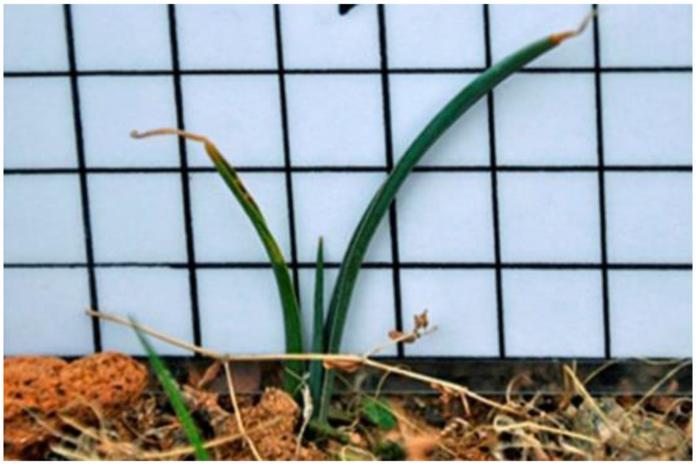


Figure 12: Size of a representative 2-year-old Joshua tree seedling with a 1-cm grid as a backdrop. Adapted from Reynolds *et al.* 2012. Used with permission.

<u>Seedlings</u>: Survival of Joshua tree seedlings, defined as plants less than 25 cm tall (10 in), requires periods of cool temperatures (Went 1957, p. 173), little to no herbivory (Esque *et al.* 2015, p. 89), summer rain (Reynolds *et al.* 2012, p. 1652), and some amount of yearly precipitation (Cole *et al.* 2011, p. 143). Seedlings (Figure 12) are more sensitive to the vagaries of desert conditions and climatic events have a strong influence on this early life stage (Esque *et al.* 2015, p. 89). The climate conditions identified above are likely required over several years to ensure a successful transition to the juvenile stage (a non-reproducing individual). Seedling survival rates can be reduced by a number of factors and are likely variable across the range. Went (1957, p. 173) found that seedlings kept at 4°C (40°F) for 2 months produced twice as many new leaves as seedlings kept at warmer temperatures, which could suggest that Joshua trees require annual cool-season exposure to low temperatures for optimal growth later during the warm season. Research in Arizona has found that day length may play an

important role in seedling growth. Seedlings grown with 10 hours of daylight and 14 hours of dark produced the longest and most leaves, with other photoperiods producing shorter and fewer leaves (McCleary 1973, p. 508). Cole *et al*. (2011, p. 147) concluded that seedlings may require several successive wet and/or cool years to survive.

One vulnerable stage in the Joshua tree life cycle is likely from germination through the time of age when the seedling has reached a certain height and the root system has become established. In the study by Esque *et al.* (2015, p. 85), researchers found that plants less than 25 cm (10 in) tall had lower life expectancy and those small plants were more susceptible to herbivory when consecutive years of drought reduced herbaceous forage (Esque *et al.* 2015, p. 89). Additionally, Went (1948, p. 250) concluded that seedlings have little chance for survival unless they can develop relatively large root systems before "the dry season starts" and Defalco *et al*. (2010, p. 246) found small size plants (<1m) are more vulnerable than large plants to periodic drought. This suggests that "climatic events may have a strong influence on early life stages of Joshua trees, either directly through drought stress or indirectly via increased herbivory during drought years" (Esque *et al.* 2015, p. 89).

Figure 13: Juvenile *Y. brevifolia* plants (foreground) at Lee Flat, Death Valley National Park, California. Photo by James Cornett. Used with permission.

Certain shrub species provide important habitat for Joshua tree seedlings and are commonly considered "nurse plants." In southern Nevada, researchers found that 92.8 percent of all seedlings were growing under various shrub species (Brittingham and Walker 2000, p. 377). Nurse plants likely provide favorable microclimates that promote seedling growth and also provide protection from herbivory (Reynolds *et al.* 2012, p. 1652). Conditions within these microclimates included higher soil moisture, decreased insolation, reduced soil temperatures, decreased evapotranspiration, increased nutrients, and lower wind desiccation (Brittingham and Walker 2000, p. 379).

<u>Juveniles</u>: Juvenile Joshua trees are defined as young, unbranched, non-reproducing plants (Figure 13). The length of time plants spend as non-reproducing individuals varies but can be up to 30 years (Esque *et al.* 2015, p. 89). There is some evidence to suggest, that similar to the

seedling stage, non-reproducing individuals are more vulnerable than reproducing individuals to the vagaries of desert conditions. For example, individual *Yucca brevifolia* less than 1 m (3.3 ft) tall were found to be more vulnerable than larger size classes to wildfires, herbivory, and periodic drought (DeFalco *et al.* 2010, p. 246; Esque *et al.* 2015, p. 89).


Figure 14: Adult *Yucca brevifolia*. Covington Flat, Joshua Tree National Park August 2017. Photo by Felicia Sirchia, US Fish and Wildlife Service.

Adults: Adult Joshua trees, defined as reproducing (flowering), multi-branched individuals, can live over 100 years and are typically between 6 and 9 m tall (20 and 31 ft), but some can be much taller (McKelvey 1938, p. 119; Figure 14). In southwestern Utah, *Yucca jaegeriana* reach heights above 6 m (20 ft) and some trees were calculated to be over 300 years old (Gilliland *et al*. 2006, p. 202). In the Antelope Valley McKelvey (1938, p. 133) described one *Y. brevifolia* that was 24 m (80 ft) tall and 2.7 m (9 ft) in circumference.

Adults are more likely to withstand drought periods and are less likely to be killed by wildfire or herbivory than juveniles or seedlings (Defalco *et al*. 2010, p. 248). Based on 20 years of monitoring (1975–1995) at three sites – Victorville, California; Cima Dome, California; and Yucca Flat, Nevada – few mature plants died over the 20-year interval (Comanor and Clark 2000, p. 45), which included an intense drought from 1989 to 1991 (Hereford *et al*. 2006, p. 19). Over the course of another long-term ongoing demographic study initiated in 1987, that included droughts from 1999–2003 (Hereford *et al*. 2006, p. 19) and 2012–2014 (Jones 2015, p. 2), only the adult stage class did not show statistically significant changes in individual mortality (Cornett 2017, p. 8).

Growth Rates: In a long-term study, Esque *et al.* (2015, p. 85) found that growth rates were variable between years [averaged 3.12 cm (1.22 in) per year (yr)], and were positively associated with precipitation. Results from this study and others indicate that growth has been relatively consistent among size and age classes over the past few decades. Similar growth rates have been found of 4 cm/yr (1.6 in/yr; Comanor and Clark 2000, p. 37) and 3.75 cm/yr (1.5 in/yr; Gilliland *et al.* 2006, pg. 202). The Esque study estimated a generation time to be between 50 and 70 years (Esque *et al.* 2015, p. 89).

5.0 SPECIES NEEDS

In this section we synthesize the information in the preceding sections to highlight the overall needs of the species. We start at the individual level and describe what each individual needs to survive and reproduce. We then move to the population level to describe overall population health and fitness, or resiliency, as measured by selected habitat and demographic factors. Finally we move to the species level to discuss what the species needs may be in terms of redundancy and representation to rebound from catastrophic events (such as wildfire) and adapt to changing environmental conditions (such as increasing temperatures).

If the needs of individuals in a population are met, allowing for an adequate population size with sufficient rate of growth, that population is considered resilient. The number of resilient populations and their distribution (and their level of connectivity) will determine the species' level of redundancy. Similarly, the breadth of genetic or ecological diversity within and among populations will determine the species' level of representation. Thus, for the species to sustain populations in the wild over time and be viable, the populations need to be able to withstand stochastic disturbance events (resiliency) and catastrophic events (redundancy), and adapt to changing environmental conditions (representation).

Individual Needs

Joshua tree individual resource needs by life-stage (Figure 15) include:

Seeds/Seedlings (less than 25 cm (10 in)

- Precipitation in an appropriate amount and frequency. Based on a 30-year average from 1981 to 2010, Joshua trees occur in areas averaging more than 82 mm (3.24 in) of rainfall and less than 738 mm (29.06 in) of rainfall per year (PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, created October 17, 2017)

- Summer precipitation. Sufficient summer precipitation for germination and to develop root systems to withstand the dry season. Across the range, precipitation increases from west (approximately 10 percent of annual precipitation) to east (approximately 35 percent of annual precipitation)

- Appropriate soils. (Includes a variety of soil types but generally on old alluvia of igneous origin; Hunning and Peterson 1973, p. 16)

- Minimum winter temperature [approximately 4º C (39º F); Went 1957, p. 178]

- Nurse plants

- Appropriate temperature range [-11°C (12°F) to 59°C (138°F), Smith *et al*. 1983, p. 16]

- Seed Dispersal/Seed Caching. Several species of rodents disperse and cache seeds, including white tailed antelope squirrels (*Ammospermophilus leucurus*) and Merriam's kangaroo rat (*Dipodomys merriami*) (Waitman *et al*. 2012, p. 6)

Juveniles (pre-reproductive individuals greater than 25 cm (10 in)

- Precipitation in the appropriate amount and frequency (see Seeds and Seedlings section above)

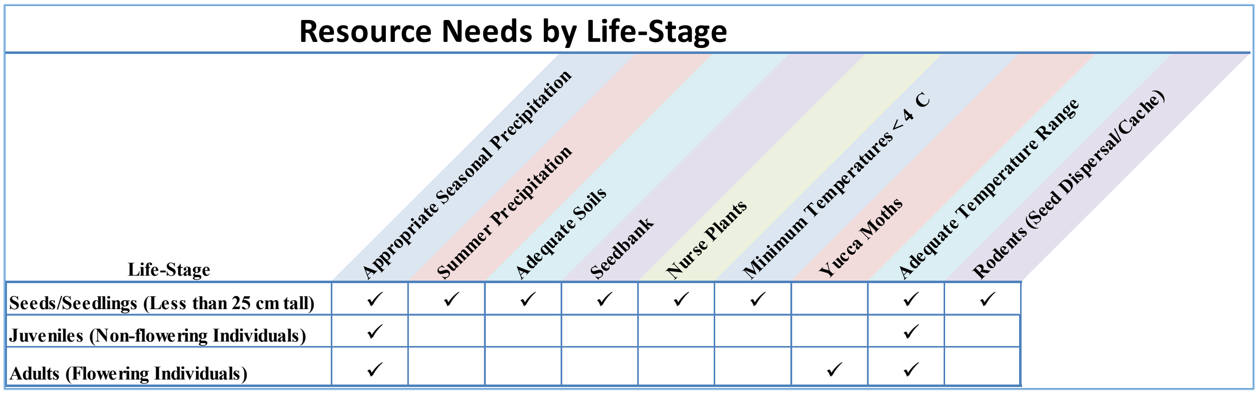
- Appropriate temperature range (see Seeds and Seedlings section above)

Adults (reproducing individuals)

- Precipitation in an appropriate amount and frequency (see Seeds and Seedlings section above)

- Pollinators. (*Yucca brevifolia* and *Y. jaegeriana* flowers are pollinated by one of two moth species, *Tegeticula synthetica* or *T. antithetica,* respectively).

- Appropriate temperature range (see Seeds and Seedlings section above)



Resource Needs by Life-Stage

Life-Stage	Appropriate Seasonal Precipitation	Summer Precipitation	Adequate Soils	Seedbank	Nurse Plants	Minimum Temperatures < 4 C	Yucca Moths	Adequate Temperature Range	Rodents (Seed Dispersal/Cache)
Seeds/Seedlings (Less than 25 cm tall)	✓	✓	✓	✓	✓	✓		✓	✓
Juveniles (Non-flowering Individuals)	✓							✓	
Adults (Flowering Individuals)	✓						✓	✓	

Figure 15: Resource Needs by Life-stage

We developed a conceptual model to visually display the relationships between nutrition, reproduction, and habitat resource functions; resource needs; factors influencing population growth; and population resiliency to facilitate our understanding of these complex interactions. (Figure 16).

Population Needs

Populations of Joshua trees need stable or increasing growth rates and enough suitable habitat distributed across the range in an appropriate size and configuration. Joshua tree populations will increase or decrease depending on the rates at which individuals germinate, mature, reproduce, and die. All these factors are likely variable across the range and depend on a combination of biotic and abiotic factors (see individual resource needs above). Joshua tree population

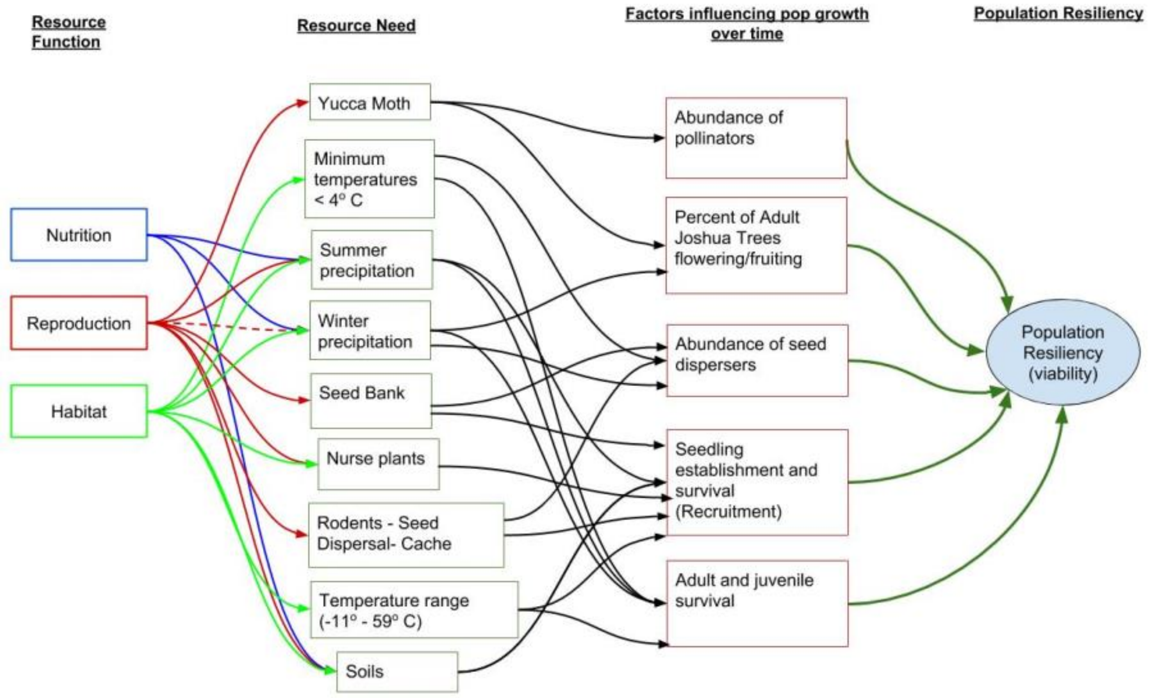


Figure 16: Conceptual Model

demographics are likely typical of other perennial desert plant species, characterized by infrequent establishment of new individuals, relatively slow growth, and long life spans (Cody 2000, p. 356).

The number of reproducing individuals required to ensure long-term persistence of Joshua tree populations is unknown but generally speaking, the larger the population, the higher the likelihood of persistence over time (Hanski 1999, p. 36), since small populations are inherently more vulnerable to extirpation due to environmental and demographic stochasticity (Given 1994, pp. 66–67).

For Joshua trees to survive and reproduce in the face of environmental variation and stochastic events, populations require an adequate number of pollinators, an adequate number of adult trees flowering and fruiting, seed dispersers, seedling survival and recruitment, and enough suitable habitat to support these population needs (see Figure 16, Conceptual Model). Additionally, responses to stochastic events are likely size-class dependent, in that young age-classes (based on plant height) are likely more susceptible to mortality (from hereon, meaning death of one or more individuals in the population) during these events than adults (Defalco *et al.* 2010, p. 246; Esque *et al.* 2015, p. 89). There should also be an adequate density of individuals across the landscape and periodic recruitment to support an age- or size-class distribution that is resilient to stochastic events (wildfire, increased herbivory, long-term frequent drought cycles, etc.).

We identified the following habitat and demographic parameters important to evaluating population needs. These parameters are similar for each of the five regional Joshua tree populations (Table 2).

Table 2: Joshua Tree Population Needs and Evaluation Criteria

Abundance and Demographics:	**Distribution:**	**Habitat Quality/Quantity**
• Number of reproducing adults • Seedling survival/recruitment • Juvenile survival/recruitment • Adult survival • Age (size) distribution	• Genetic diversity • Connectivity • Ecological setting	• Suitable Habitat • Management/Conservation potential • Ecological Diversity

Species Needs: Representation and Redundancy

Redundancy

Redundancy describes the ability of a species to withstand catastrophic events as measured by the number of populations, their resiliency, and their distribution and connectivity. Redundancy gauges the probability that the species has a margin of safety to withstand or recover from catastrophic events and spreads risk among multiple populations to minimize the potential loss of those populations or the species from catastrophic events. Catastrophic events are rare occurrences, typically of a finite duration, that may result in severe negative impacts to one or more populations or occurrences within populations (e.g., floods, fire, drought, etc.). The greater the number of populations or occurrences a species has distributed over a larger landscape, the better it can withstand catastrophic events. Thus, redundancy for both species depends on the persistence through time of connected local populations (via dispersal) to maintain large regional populations across the range.

Representation

Representation is measured by the breadth of genetic or ecological diversity within and among populations; representation is used to evaluate the probability that a species is capable of adapting to environmental changes. Shaffer and Stein (2000, pp. 301–302) related representation to the conservation of species within the "array of different environments in which it occurs" or areas of significant geographic, genetic, or life history variation (Carroll *et al*. 2010, entire; Wolf *et al*. 2015, entire), termed here as ecological settings Thus, representation for both species depends on the plant's persistence through time within the array of ecological settings it currently occupies, with enough genetic diversity to adapt to changing environmental conditions.

To summarize species needs, Joshua trees rely on habitat elements that include appropriate soil types, adequate amounts of precipitation [82 mm (3.24 in) and less than 738 mm (29.06 in)], and ambient temperatures within the range of tolerance for this species [-11–59°C (12–138°F)]. To reproduce successfully, individuals need pollinators, seed production, nurse plants, seed caching rodents, and suitable climate conditions. To perpetuate redundancy, numerous local populations need to be distributed widely across the landscape with some degree of connectivity to maintain redundancy and withstand catastrophic events. Finally, to maintain representation, which is needed by the species to respond to changing environmental conditions, genetic diversity must be maintained by preserving individuals or populations that are morphologically, geographically, or ecologically diverse.

6.0 SPECIES STATUS – CURRENT CONDITION

In this section we describe our analysis of the current condition of Joshua trees. We begin with a discussion of the potential threats across the landscape that may affect the current condition. Next, we outline the criteria we have used to evaluate population resiliency and discuss those criteria as they relate to each population. Lastly, we evaluate the species current condition in terms of its resiliency, redundancy, and representation.

Uncertainties

While we have used the best available information to determine the current status of Joshua trees throughout their range, we acknowledge the following uncertainties in our current condition assessment:

- Joshua tree population abundance and trends
- Regional population structure and connectivity
- Natural variability in demographic vital rates across the range
- Effective population size
- Joshua tree population structure's influence on dispersal of yucca moths
- Joshua tree occupancy and distribution within the current mapped (modeled) distribution
- Effects of an altered fire regime on demographic vital rates
- Relationship between recruitment rates and changing environmental conditions (e.g., increasing temperatures and altered drought patterns)
- Urban area influence on demographic vital rates and population structure
- Grazing effects on Joshua tree populations
- Yucca moth population abundance and trends

Stressors Potentially Affecting the Current Condition of *Yucca brevifolia* and *Yucca jaegeriana* Populations

In this section we discuss the stressors that could potentially influence the current condition of *Yucca brevifolia* and *Y. jaegeriana*. We use the term *stressor* to refer to any action, event, or environmental condition that is known to or is reasonably likely to negatively affect individuals of a species. This includes actions, events, or conditions that have a direct impact on individuals as well as those that affect individuals through alteration of their habitat or resource needs. We use the term generally to describe the source of the action, event, or environmental condition that negatively affects the species, or the action, event, or environmental condition itself. The stressors identified below are the stressors we determined are most likely to influence the current condition for the two species. Other low-level stressors may be impacting the two species on an individual plant level but these stressors are considered the baseline stressors natural to the areas where the two species occur.

Stressors may disproportionally affect small-sized *Yucca brevifolia* and *Y. jaegeriana* plants and young age-classes as they may be more vulnerable to potential stressors such as wildfires, prolonged drought, and herbivory (DeFalco *et al.* 2010, pp. 246–247; Esque *et al.* 2015, p. 89). Figure 17 illustrates effects pathways we modeled that could have the potential to influence the current condition of *Y. brevifolia* and *Y. jaegeriana*. Because life history, individual needs, population needs, species needs, and general ecology of *Y. brevifolia* and *Y. jaegeriana* are congruent we assume the effects pathways are the same for both species. We evaluated impacts from the following stressors on both species: (1) wildfire and invasive plants, (2) changing climate trends (e.g., increased temperatures and longer, more frequent drought periods), (3) habitat loss, (4) herbivory, (5) overutilization, and (6) nitrogen enrichment from air pollution.

Yucca brevifolia

Altered Fire Regimes and Invasive Annual Grasses

Wildfires have not been historically common occurrences in the Mojave Desert (Brooks and Matchett 2006, p. 148), but they have increased in frequency in recent decades (Brooks *et al.* 2013, p. 2). Altered fire regimes and the prevalence of invasive annual grasses are closely coupled; therefore, we have combined the discussion of each into a single stressor discussion.

Because fires have not been historically common occurrences in southwestern deserts, native scrub vegetation communities in the Mojave Desert have not generally evolved or adapted to withstand effects from fire (Abella 2010, p. 1249). As a result, native plants in the Mojave Desert tend to be vulnerable to fire. However, over recent decades the frequency of fires in the Mojave Desert has increased, largely due to the proliferation of highly flammable invasive annual grasses that provide increased fuel loads for fires (Brooks *et al.* 2013, p. 2) as well as provide more continuity across open spaces between shrubs. *Yucca brevifolia* plants are not considered to be well-adapted to fire (Abella 2010, p. 1249).

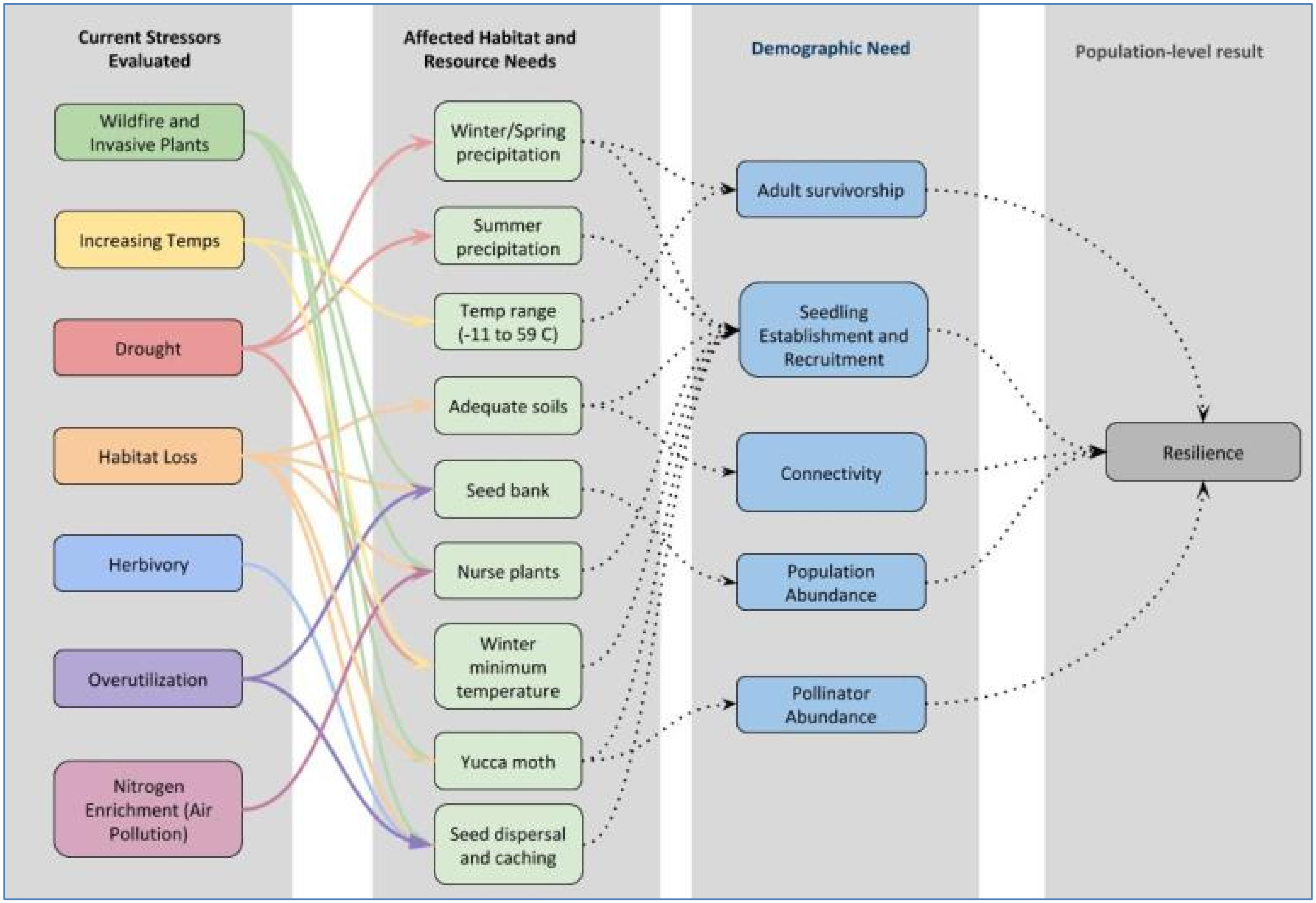


Figure 17: Conceptual model showing the possible relationships between potential stressors, habitat and resource needs, demographic needs, and resiliency for *Yucca brevifolia* and *Y. jaegeriana*. Dashed lines indicate more research is needed to better understand the relationship between habitat needs, demographic need, and population resilience

Between 1980 and 2004, fires have predominantly occurred in the mid-elevation zone (Brooks and Matchett 2006, p. 153), which largely defines the range of *Yucca brevifolia* and *Y. jaegeriana*, and to a lesser degree lower elevation zones. Mid-elevation zones in particular experience flushes of invasive annual grasses, especially following years of above average precipitation, and this has increased the intensity of fires within the region (Brooks and Matchett 2006, p. 158). Within Joshua Tree National Park, California, for example, once-dominant native grasses have been replaced in many areas by more flammable invasive annual grasses, which bridge gaps between woody plants and as a result tend to carry fires across larger areas (Brooks and Matchett 2006, p. 162). As fires occur, more invasive grasses re-colonize and proliferate within the burned area, causing more frequent and increasingly larger fires. Within the park, records demonstrate that fires caused by lightning strike prior to 1965 tended to be small, not typically spreading more than tens of meters from the strike. More recent fires have measured in the thousands of acres, and this increase in fire size could cause significant shifts in vegetation communities in the park within a time frame of decades (Holmgren *et al.* 2009, p. 6).

This trend of increasing fire size has also been documented across the broader Mojave Desert. For example, the Southern Nevada Complex fires, which were started by lightning during the summer of 2005, burned almost 740,000 acres of Mojave and Great Basin Desert habitat in southeastern Nevada, southwestern Utah, and northeastern Arizona. This exceeded the total acres burned within the Mojave Desert within the entire preceding 25-year period (Brooks and Matchett 2006, p. 159). The spread of these fires was driven by unusually high amounts of invasive annual grasses as well as high winds. This resulted in a rapid rate of spread that consumed most grasses and herbaceous species and some shrubs and scattered trees (BLM 2011, p. S-5). In its final post-fire rehabilitation report, the BLM noted that fire severity varied throughout the burned area, with 15 percent of the burned area experiencing either no vegetation mortality or very low mortality (0–5 percent), 71 percent of the burned area experiencing low-to-moderate vegetation mortality (6–60 percent), 13 percent of the burned area experiencing moderate vegetation mortality (61–85 percent), and 1 percent of the burned area experiencing high vegetation mortality (86–100 percent) (BLM 2011, p. 10).

While invasive grasses are linked most directly with increasing fire frequency, larger fires, and more severe fires in the southwest deserts, there have been instances where native plant species have caused large fires as well. Following winters with unusually high amounts of precipitation, native perennial grasses and native annual forbs have been observed to flourish, with high amounts of above ground biomass filling the interstitial spaces between shrubs (McAuliffe 2016, p. 58; Esque *et al*. 2013, p. 2). During the summer months as plant material becomes drier, these species may also carry fire through the interstitial spaces between shrubs, having the same results as the presence of invasive grasses would have. However, while this has been demonstrated as a potential source of more frequent, larger, and more severe fires, anticipated shifts in precipitation leading to less winter moisture may significantly diminish the potential for native species to flourish in this manner.

Direct effects to *Yucca brevifolia* from fire include immediate mortality and reduced survivorship over time. For example, above normal precipitation in 1998 resulted in increased annual plant production that fueled many large fires in the Mojave Desert (DeFalco *et al.* 2010, p. 243). The mortality rate (from hereon, the term means the proportion of deaths in a population) for burned *Y. brevifolia* was approximately 80 percent compared to 26 percent for unburned plants. Plants that were shorter than one meter in height were especially susceptible, as many died immediately after being burned. Young plants are most vulnerable to fire because they have their active meristems close to the ground. Overall survival for all size classes except for the tallest and oldest plants had declined to the same level by 2004. As noted by the researchers, the high mortality recorded in this study is consistent with high mortality documented in other studies, including 90 percent mortality 6 years after a fire in Joshua Tree National Park and 64–95 percent mortality at various sites between 1–47 years after fires in California portions of the Mojave and Sonoran Deserts. This study provides evidence that: (1) an abundance of invasive annual grasses may lead to larger fires than are historical, and (2) *Y. brevifolia* plants are generally not well adapted to fires, with resulting high mortality rates, particularly those plants in smaller size classes. Other indirect effects to *Y. brevifolia* from fire might include degraded seed bank, loss of aboveground vegetation that could serve as nurse plants to seedlings, and alteration in seed-caching rodent dynamics within *Y. brevifolia* stands.

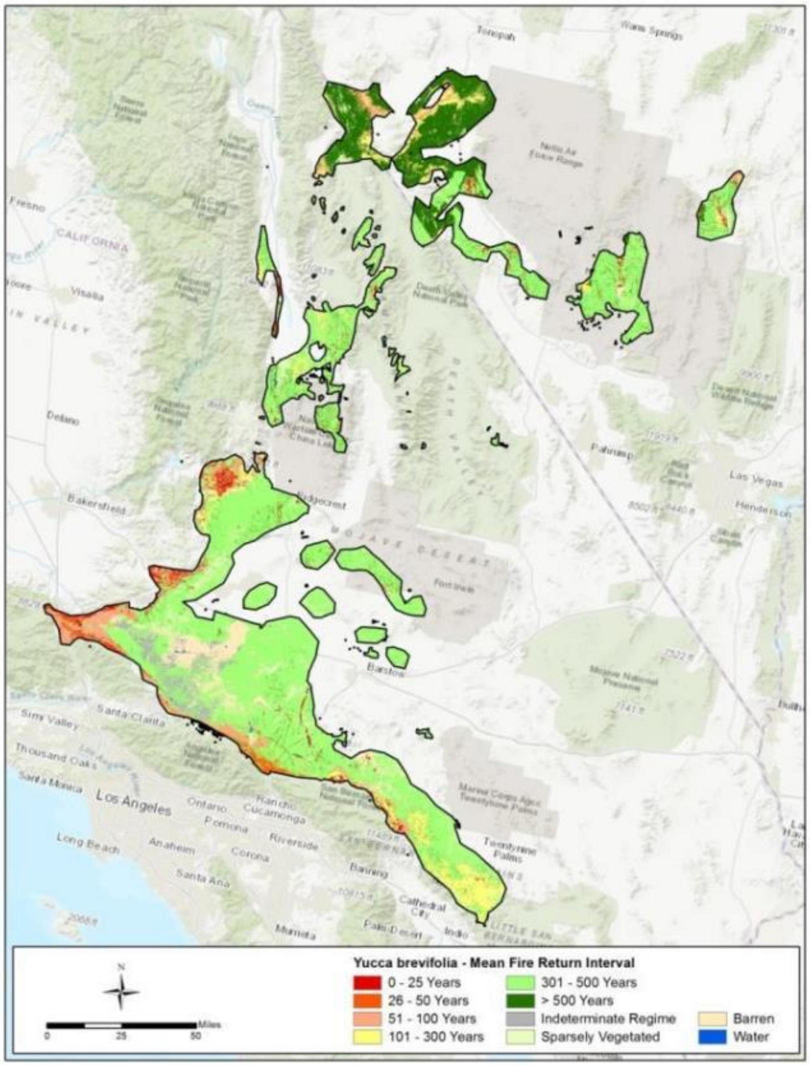


Figure 18: Estimated current mean fire return interval within *Yucca brevifolia* population units

Contrary to these results, surveys conducted on the U.S. Air Force's Edwards Air Force Base approximately 18 years after a fire burned over 500 acres of desert habitat that contained *Yucca brevifolia* indicated that the number of individual *Y. brevifolia* plants increased post-fire (USAF 2017, pp. 1-3). There was also evidence that burned trees sprouted after the fire occurred. However, because the initial data collected before the fire relied on methods that could have underestimated small-size *Y. brevifolia* plants within the burned area, it is possible that these individuals, which as stated previously are more susceptible to the effects of fire, could have been lost during or after the fire and not included in the final analysis.

As illustrated in Figure 18, fire return intervals across *Yucca brevifolia* population units are generally greater than 300 and 500 years, which is considered a long fire-return interval

(Sugihara *et al*. 2006, p. 66). The western portion of the YUBR South population occupies more of an urban-wildland interface, and reduced fire return intervals in these areas range from 0–25 years to 101–300 years. This proximity to urban areas may lead to increased vulnerability to fire than the eastern portion of the population and the broader YUBR North population. The effects to individual plants described above (i.e., direct mortality and diminished survival over time, degraded seed bank and diminished germination and recruitment) could magnify to broader population and species level impacts as increasingly larger patches of individuals are directly or indirectly affected by fire. The majority of the *Y. brevifolia* range currently experiences long fire-return intervals. Therefore, wildfire and fire frequency is unlikely to be currently influencing the current condition of the *Y. brevifolia* species at a population or species scale.

Climate Trends

Various changes in climate (e.g. increased temperatures, drought, precipitation timing) may have direct or indirect effects on species. These effects may be positive, neutral, or negative, and they may change over time, depending on the species and other relevant considerations, such as threats in combination and interactions of climate with other variables (for example, habitat fragmentation; IPCC 2014, pp. 4–11). Changes in climate as a result of global warming may also influence or exacerbate other stressors on a species. There is scientific evidence for continued multi-decadal warming across the Earth's surface, with each of the previous three decades experiencing progressively warmer temperatures than any preceding decade since 1850 (IPCC 2014, entire). For the southwest U.S., temperatures have been increasing in past decades and since 1950 the region has experienced hotter temperatures than in any period during the past 600 years (Garfin *et al.* 2014, p. 464). Overall, 2016 was the hottest year ever recorded globally, and average temperatures have increased by approximately 1.0 to 1.2°C above pre-industrial levels (WMO 2018, p. 4; Polley *et al*. 2013, p. 493). The southwest U.S. is projected to be affected particularly severely by prolonged drought, fewer frost days, warmer temperatures, greater water demand by plants, and an increase in extreme weather events (Jepson *et al*. 2016, p. 49; Cook *et al*. 2015, entire; Archer and Predick 2008, pp. 23–24). Many of these phenomena may be influencing the current condition of *Yucca brevifolia*.

Increasing maximum summer temperature:

As discussed previously in the Habitat section, *Yucca brevifolia* does not generally occur in the hotter and dryer lower elevation areas of the Mojave Desert. Rowlands (1978, p. 179) posited that *Y. brevifolia* distribution across the Mojave Desert may be generally constrained by summer maximum temperature and winter minimum temperature. As illustrated in Figure 19, average summer maximum temperatures are generally warmer in the southern portion of the *Y. brevifolia* range.

Individual *Yucca brevifolia* plants have demonstrated the ability to survive temperatures up to 59°C (138°F) (Smith *et al*. 1983, p. 16), although plants in general tend to maintain optimal photosynthetic activity within a range of more mild temperatures. Increasing maximum summer temperature may affect *Y. brevifolia* populations, as evidenced by a model developed by Barrows and Murphy-Mariscal (2012, p. 34) that predicted a 90 percent decline in *Y. brevifolia* distribution within Joshua Tree National Park, California, with a 3ºC increase in July temperature. However, the model also identified climate refugia where this species would persist, e.g., steep north facing slopes and higher elevations in the Park (Barrows 2018, pers. comm.). While this is a future condition scenario, it is unknown to what magnitude increasing temperatures have already impacted *Y. brevifolia* at a population or species level, as maximum summer temperatures have been increasing over past decades. However, this model was applied to a small portion of the population and there is no documentation that increasing maximum summer temperature is influencing the current condition of *Y. brevifolia* at a population or species scale.

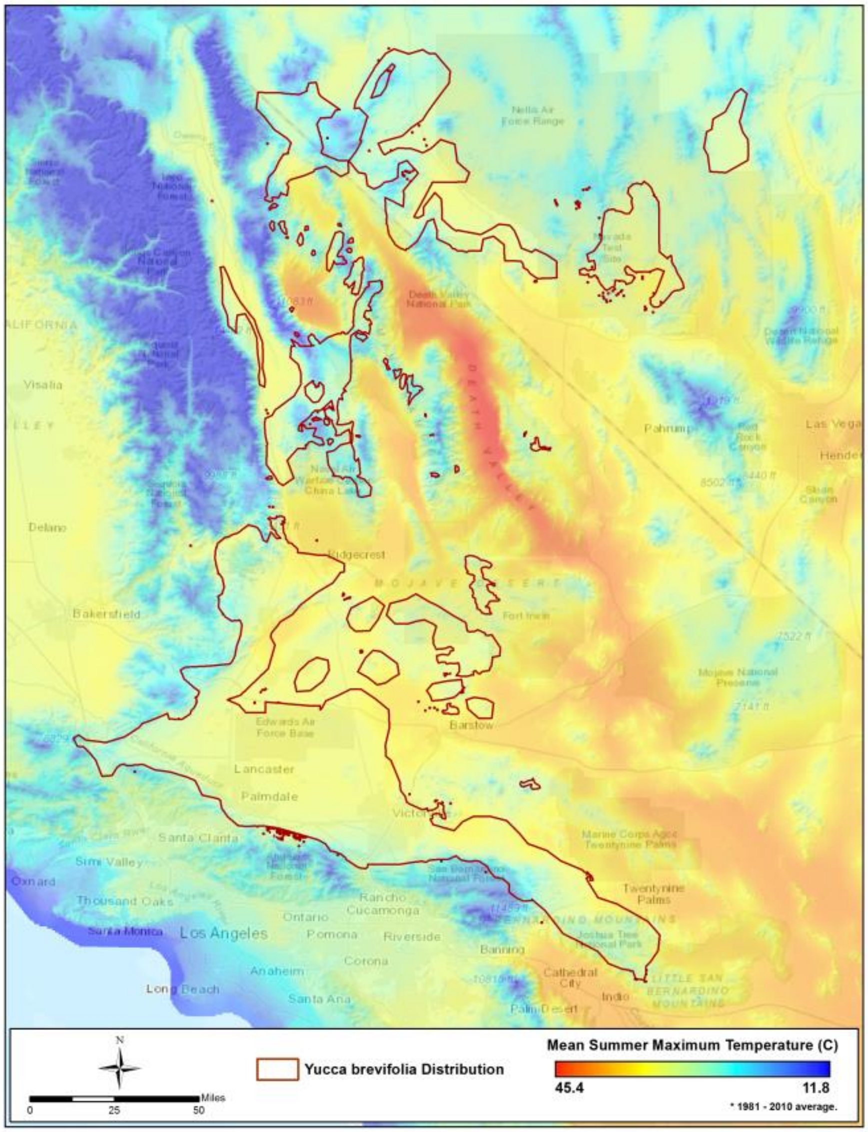


Figure 19: Mean summer temperatures within *Yucca brevifolia* population units

Increasing minimum winter temperature:

As discussed previously in the Species Needs section, and based on greenhouse experiments performed by Went (1957, entire), exposure to short periods of cold temperatures [below approximately 4°C (39°F)] may lead to optimal growth, reproduction, and recruitment for *Yucca brevifolia* individuals. However, we lack information to indicate whether these results apply to field conditions, and are unable to determine whether increasing minimum winter temperature has any effect on growth rate or other physiological parameters that may affect *Y. brevifolia* individuals. We are unable to determine which species (*Y. brevifolia* or *Y. jaegeriana*) was used in these greenhouse experiments. However, because life history, individual needs, population needs, species needs, and general ecology of *Y. brevifolia* and *Y. jaegeriana* are congruent we assume the effects and magnitude of effects would be the same for individuals of both species.

As illustrated in Figure 20, average winter minimum temperatures are generally warmer in the southern portions of *Yucca brevifolia* populations and transition to generally cooler in northern portions. Rowlands (1978, p. 179) posited that *Y. brevifolia* population distribution across the Mojave Desert may be generally constrained by summer maximum temperature and winter minimum temperature. If this constrained occurrence is considered in terms of population and species level effects, we could assume that the range of *Y. brevifolia* could shift to more northern areas or to higher elevations where temperatures profiles are more accommodating to species needs. However, the available information does not indicate that increasing minimum winter temperature has had any such effects on *Y. brevifolia* current abundance at a population or species scale.

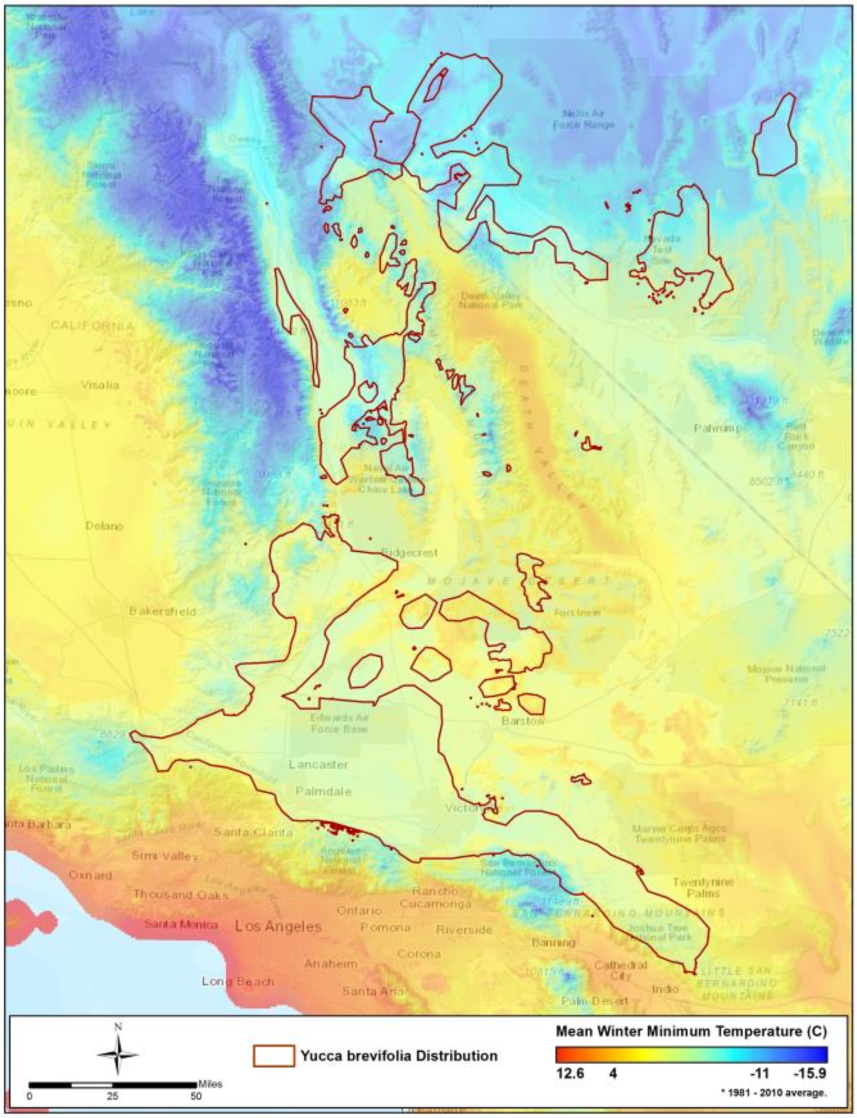


Figure 20: Mean Winter Temperature - *Yucca brevifolia*. Based on Smith *et al.* 1983, lower limit threshold is -11 C. Based on Went (1957), optimal seedling growth occurs at 4 C.

Altered summer and cool season precipitation:

As discussed previously in the Species Needs section, adequate amounts of precipitation throughout the year are likely to be important to *Yucca brevifolia* individuals at all life stages. Studies on *Y. jaegeriana* have indicated that summer precipitation may be important to individual plants, as wetter summers may result in larger annual or episodic germination events (Reynolds *et al.* 2012, pp. 1648–1653; Esque *et al.* 2015, p. 87). Research conducted in Piute Valley, Nevada, found that greatest seedling emergence for *Y. jaegeriana* occurred during spring and summer, when increased soil moisture was accompanied by warm soil temperatures, indicating adaptation to regular summer rainfall. In general, more summer and cool season precipitation seems to result in more successful germination for individuals, leading to increased abundance within populations. Because life history, individual needs, and general ecology of *Y. brevifolia* and *Y. jaegeriana* are congruent we assume wetter summers would result in the same effects for *Y. brevifolia*. *Yucca brevifolia* seeds appear to germinate any time after a rain after seed shedding, which occurs in summer (Went 1948, p. 250). Reynolds *et al.* (2012, p. 1652) also note that it is possible factors other than warm, wet conditions may be important for optimal emergence, but we do not have information to examine this possibility.

As noted by Rowlands (1978, p. 179), *Yucca brevifolia* seems to occur more in areas that do not receive substantial summer rainfall as compared to *Y. jaegeriana* distribution. Precipitation tends to be localized in nature across the range of *Y. brevifolia* and we lack specific information about how historic precipitation patterns have affected the current condition of the species. As illustrated in Figure 5, there is a general trend of less precipitation in the more western *Y. brevifolia* population units. Based on this pattern and on the studies cited above, it is possible that germination rates could vary within *Y. brevifolia* population units along a precipitation gradient. However, we have no information about whether a critical threshold exists for the influence that precipitation may have on germination and recruitment. Because germination and recruitment at some level of success is likely occurring throughout the range of *Y. brevifolia*, and because we lack information that would indicate otherwise, we are unable to determine whether altered summer and cool season precipitation patterns are influencing the current condition of *Y. brevifolia* at a population or species scale. If germination and recruitment of individuals is being diminished as precipitation pattern and abundance is altered, the loss of individuals could have detrimental effects at the population or species scale by reducing abundance of *Y. brevifolia* at each scale.

Prolonged periods of drought:

Climate change impacts in the southwest U.S. to date have included increased frequency and intensity of extreme weather events such as drought (Garfin *et al.* 2014, p. 464; Archer and Predick 2008, pp. 23–24). Additionally, the severity of drought events could be intensified due to consistently high temperatures in conjunction with low precipitation (Archer and Predick 2008, p. 24).

Drought has been demonstrated to potentially influence decadal demography in *Yucca brevifolia* by reducing survival rates in juvenile individuals (less than 1 m tall; Defalco *et al*. 2010, p. 246). It has also been demonstrated to influence demography in *Y. brevifolia* by increasing herbivory of individual young (less than 25 cm tall) plants (Esque *et al.* 2015, p. 87). Periods of drought may generally affect individuals by reducing the amount of water available to plants at times when adequate rainfall would lead to optimal germination and recruitment. Reduced recruitment over time could lead to contraction of populations. Prolonged, intense droughts within the broader range of *Y. brevifolia* occurred during the 1930s Dust Bowl, 1950s, and 1990s–2000s, with dramatic impacts on the landscape that included native vegetation mortality events (Notaro *et al.* 2012, p. 1365). However, because of the limited scope of these studies and historical drought periods experienced by the species, we do not have evidence to determine whether periods of prolonged drought are currently impacting *Y. brevifolia* at a population or species scale.

CO_2 enrichment:

The greenhouse effect is the result of elevated atmospheric levels of CO_2, the effects of which may stimulate plant growth and reduce the negative effects of drying in a warmer climate via increasing plant water use efficiency (Polley *et al*. 2013, p. 498). However, this effect may be mediated by other conditions related to increasing temperatures, particularly soil water availability. Net effects could be numerous and varied, including modifications to forage quality and quantity, as well as shifts in general species distributions. For example, Smith *et al*. (2000, p. 81) demonstrated that new shoot production of dominant perennial shrubs doubled following a 50 percent increase in atmospheric CO_2 in a high rainfall year, while elevated CO_2 did not increase perennial shrub production in a drought year. However, we do not have species-specific information to indicate how elevated atmospheric CO_2 has affected *Yucca brevifolia* populations. As a result, we do not consider CO_2 enrichment to be a stressor driving the current condition of *Y. brevifolia* at a population- or species-scale.

Habitat Loss

The loss of habitat occurs at various extents across the range of *Yucca brevifolia.* Because habitat loss may result in the permanent removal of plant cover and loss of soil structure, it can negatively affect the landscape condition for current *Y. brevifolia* populations and may constrain future range expansion. The discussion here presents presumed stressors and how each could potentially influence *Y. brevifolia* population dynamics, as well as land management factors that could potentially alleviate or exacerbate these effects. Contributors to large-scale habitat loss across the range of *Y. brevifolia* may include urban expansion and development, military installation expansion and training activities, renewable energy development, grazing, and off-highway vehicle (OHV) use.

Urban expansion and development:

Urban and metropolitan areas currently overlap with approximately 2.2 percent of the range of *Yucca brevifolia*, and expansion and development in these areas may permanently remove habitat. In particular, the YUBR South population overlaps the cities of Victorville, Hesperia, Palmdale, Lancaster, and Ridgecrest; and towns of Yucca Valley, Apple Valley, and Antelope Valley. However, our evaluation of the characterization of recent development within YUBR South surrounding these communities where Joshua trees occur has not entirely been high density development (complete removal of habitat), but mostly small 0.2–0.4 ha (0.5–1.0 ac) ranchette type development with often larger undeveloped islands providing habitat for Joshua trees interspersed throughout. Additionally, Federal agencies, the State of California, and several of these communities have adopted and implemented laws and ordinances that protect *Y. brevifolia* from harvesting and removal to some degree (Table 3). By comparison, the YUBR North population has experienced much less development. Urban and metropolitan areas within the YUBR South population comprise a small proportion of overall *Y. brevifolia* habitat. Therefore, habitat loss due to urban development may result in some loss of individuals across the landscape, but it is not likely to influence the current condition of *Y. brevifolia* at a population- or species-level scale.

Table 3: Current Law or Ordinance Protecting or Regulating Removal of Joshua Trees

Jurisdiction	Law/Ordinance	Joshua Tree Protections
NPS	Enabling legislation for National Park; California Desert Protection Act, Code of Federal Regulations	Established Death Valley and Joshua Tree National Parks and Mojave National Preserve; Joshua trees are protected in these areas.
BLM	California Desert Protection Act; Code of Federal Regulations	Designated 69 wilderness areas as additions to the National Wilderness Preservation System within the California Desert Conservation Area. Joshua trees are protected in these areas.
USFS	Native Plant Materials Policy; USFS Manual; Wilderness Act	Promote native plant use in restoration; Plant protections
DoD	Sikes Act	Requirement of INRMPs for military installations
Arizona	Arizona Native Plants-Native Plant Rules	*Yucca jaegeriana* are salvage protected restricted native plants and can only be collected with a permit from the Arizona Department of Agriculture
California	California Desert Native Plants Act	California law that prohibits unlawful harvesting of desert plants on both public and privately owned lands, without a permit, in all CA deserts.
Nevada	State Statutes	Collection regulated.
City of Hesperia, CA	PL-16, Protected Native Vegetation and PL-17, Protected Plant Policy	Joshua trees on single-family residential tract, multiple-family residential, commercial, and industrial developments are identified and avoided, if possible. If not possible, transplanting or adoption is an alternative.
City of Palmdale, CA	Joshua Tree and Native Desert Preservation	City ordinance that protects and preserves desert vegetation, and in particular *Yucca brevifolia*.
City of Victorville, CA	City Ordinance No. 1224, Joshua Tree Inspection Program	Under this ordinance, *Yucca brevifolia* on undeveloped lands are protected. Grading a site, removing or damaging plants prior to completing the inspection procedures may result in fines and/or penalties for the property owner/developer.

Jurisdiction	Law/Ordinance	Joshua Tree Protections
Yucca Valley, CA	City Ordinance 140, Desert Native Plant Protection	A permit issued by the Community Development Director is required to remove *Yucca brevifolia*, with the exception of the fruit. Applies on all private lands within the town of Yucca Valley and public lands owned by Yucca Valley.

Military activities:

Portions of the YUBR South population overlap with the Naval Air Weapons Station at China Lake (U.S. Navy), Fort Irwin National Training Center (U.S. Army), Edwards Air Force Base (U.S. Air Force), and the Marine Corps Air Ground Combat Center (U.S. Marine Corps). Portions of the YUBR North population overlap with the Naval Air Weapons Station at China Lake and Nellis Air Force Base (U.S. Air Force). Development, land use changes and training activities within military installations can degrade and potentially remove *Yucca brevifolia* habitat.

The Department of Defense (DoD), with the assistance of the Service and the states, is responsible under the Sikes Act (16 U.S.C. 670a–670f, as amended) for carrying out programs and implementing management strategies to conserve and protect biological resources on its lands. Integrated Natural Resources Management Plans (INRMPs) are planning documents that allow DoD installations to implement landscape-level planning to provide for the management of natural resources, including fish, wildlife, and plants, without any net loss in the capability of an installation to support its military mission.

The Edwards Air Force Base INRMP describes *Yucca brevifolia* as the “most prominent and widespread naturally-occurring treelike species on Edwards Airforce Base” (USAF 2015, p. 66). Plants occur in low densities in creosote and saltbush scrub habitats throughout the base. Environmental Management on the base encourages conservation of Joshua trees wherever feasible and the most current revegetation plan recommends replacement or replanting *Y. brevifolia* to maintain the diversity of natural habitats.

While *Yucca brevifolia* is not as widespread at the Marine Corp Air Ground Combat Center, the species does receive protections offered by the installation’s INRMP. These measures include an emphasis on using native plant species, including *Y. brevifolia*, for restoration of disturbed areas, inclusion of the species in basewide environmental awareness training for personnel, and inclusion of the species in vegetation and sensitive plant survey and mapping efforts. In addition to INRMP measures, *Y. brevifolia* is protected by an existing buffer along the perimeter of the installation where military training is prohibited. Most individual *Y. brevifolia* plants occur within this buffer area. Further protections exist for the two primary areas on the installation where *Y. brevifolia* occurs (i.e., Sandhill and Restricted Area) where training is restricted and general ecological protections are enforced.

Information from the China Lake INRMP indicates that Joshua Tree Woodlands is identified as a sensitive vegetation community and considered in land use planning activities (Navy 2014, p. 3-3). Limited public access and high levels of protection are currently provided for this vegetation community in some areas on the installation due to cultural resources, endangered wildlife species, and wetlands protections, which likely provide incidental benefits to individual plants. Current management is accomplished through the conservation of Joshua tree woodland habitats, fire management, and non-native plant control (Navy 2014, p. 3–41). Avoidance and minimization measures identified in the INRMP include avoidance of removing large Joshua trees and management of wild horses and burros to reduce their numbers.

On Fort Irwin both *Yucca brevifolia* and *Y. jaegeriana* occur in several areas throughout the installation. There are extensive stands of *Y. brevifolia* with large, many branched individuals in the Western Expansion Area of the installation. Avoidance and minimization measures identified in the Fort Irwin INRMP include approval from the Natural and Cultural Resources Section for removal of *Y. brevifolia* and *Y. jaegeriana* in proposed project footprints. If removal is necessary, plants are relocated to sites with the same orientation and similar characteristics as their original sites to reduce the risk of tree mortality (Army 2006, p. 182).

Both *Yucca brevifolia* and *Y. jaegeriana* occur on the Nellis Air Force Base. The INRMP, which includes the Nevada Test and Training Range (NTTR), indicates that Joshua tree is a plant that may occur at higher elevations within the creosote bush-white bursage and the blackbrush communities on the installation (USAF 2010, pp. 118–119) and that bird species diversity increases where Joshua trees are present. While avoidance and minimization measures have not been identified to reduce effects to Joshua trees, a need has been identified to understand and manage existing vegetation on the base (USAF 2010, p. 120) with an identified goal to conserve unique plant communities (USAF 2010, p. 123), which could provide incidental benefits to plants.

Approximately 24.6 percent of the *Y. brevifolia* current mapped distribution occurs on military lands (Table 1). Based on available information, there is no indication that military activities have influenced the current condition of *Y. brevifolia* at a population or species scale. Additionally, incorporation of INRMP's on the DoD installations may provide management and conservation benefit to plants as identified above.

Renewable energy development:

Renewable energy development has degraded *Yucca brevifolia* habitat and resulted in habitat loss within the range of the species. Examples of projects include solar, wind, and geothermal development. However, it is unknown how this loss of habitat has affected populations, and because the total area of habitat already lost to renewable energy development comprises a relatively small proportion of the *Y. brevifolia* range there continue to be large expanses of habitat and potential refugia available. Within the range of *Y. brevifolia*, approximately 1.2 percent of current mapped distribution has been developed for renewable energy. Because of this small proportion, loss of habitat due to renewable energy development is unlikely to be influencing the current condition of *Y. brevifolia* at a population or species scale.

Grazing:

While grazing allotments overlap a relatively large proportion of the *Yucca brevifolia* current mapped distribution (approximately 32.2 percent), many of these allotments are not actively being grazed. Effects from grazing on *Y. brevifolia* individual plants include impacts from herbivory, trampling of young plants, or loss of soil structure. However, because *Y. brevifolia* has remained persistent on the landscape in spite of grazing effects, we assume that livestock use is a low level stressor that does not impact the current condition of *Y. brevifolia* at the population or species scale.

Off-Highway Vehicle Use:

Authorized and unauthorized OHV use likely occurs throughout a large proportion of the *Yucca brevifolia* range. Where use is most intense, disturbance and habitat loss can be severe, with vegetation largely removed and soil structure compromised. This could affect *Y. brevifolia* by degrading the seed bank and removing nurse plants that benefit germination. However, over broader areas OHV use is more generally diffuse in nature, resulting in fragmented effects that do not result in complete habitat loss. Therefore, while some *Y. brevifolia* individuals are being impacted by OHVs, based on the available information OHV use is unlikely to be impacting the current condition of *Y. brevifolia* at the population or species scale.

Herbivory

Herbivory of *Yucca brevifolia* leaves and periderm by desert woodrats, black-tailed jackrabbits, and other granivores has been documented (Esque *et al.* 2015, p. 6; Cornett 2017, p. 9). Herbivory pressure from various granivores, working in tandem with the typical low germinability of *Y. jaegeriana* seeds in the soil, has been linked with reduced seedling germination and establishment (Reynolds *et al.* 2012, p. 1652). Esque *et al.* (2015, p. 85) found that herbivory of *Y. brevifolia* plants by black-tailed jackrabbits in years one and two of their study caused 45 percent and 31 percent mortality, respectively. Rodent, rabbit, hare, or mule deer herbivory was recorded within sites monitored across the range of *Y. brevifolia* and led to varying degrees of juvenile plant mortality (Cornett 2017, Table 1). However, there is no information to indicate that herbivory has negatively influenced population dynamics on a population or species scale.

Disease

A single study on *Yucca brevifolia* has documented disease in the form of leaf spot (necrotic lesions) or blight associated with three fungal organisms (Wolf 1964, pp. 18–21). The three fungal organisms that were attributed in this study to causing disease on the leaves of *Yucca brevifolia* were identified as: *Staganospora gigantea, Leptosphaeria concentrica* and its conidial stage (asexual reproductive stage) *Coniothyrium concentricum,* and *Pleospora ellisii*. The fungal organisms, in severe instances cause the affected leaves to die. This study found that *S. gigantea* as being the primary cause and the other organisms being secondary invaders or complicating agents, but still contributing to the overall disease (Wolf 1964, p. 21). The study was only concerned with identifying the specific organism causing the leaf spot and did not report on degree, extent, or prevalence of the disease on the species and we know of no other reported diseases which may impact *Yucca brevifolia*. Based on the limited nature and information related to this study, the lack of mention of the disease in any other studies on the species, and lack of reported die-offs or other detrimental impacts as a result of this or other unknown diseases, we have determined that there is no information to indicate that disease has negatively influenced the current population dynamics on a population or species scale.

Overutilization

Overutilization of *Yucca brevifolia* (such as illegal harvesting of plants) is not likely to be a significant stressor to the species, as no published research is available to inform otherwise. There are state and local regulations that prohibit the harvesting of *Y. brevifolia* plants throughout portions of the range. In California, the California Desert Native Plant Act (CLI 1981, entire) restricts harvesting of *Y. brevifolia* plants. In California, harvesting on BLM land requires a permit and tag (NDF undated, p. 1), harvest of plants on U.S. Forest Service and National Park Service (NPS) lands is prohibited (Forest Service undated, p. 1; ECFR 2018, p. 1), and harvesting on other public and private land may be regulated by local ordinances (see Table 3).

Nitrogen Enrichment (Air Pollution)

Allen *et al*. (2009, p. 13) demonstrated that in Joshua Tree National Park, within the range of *Yucca brevifolia*, reactive atmospheric nitrogen from urban areas that becomes deposited in the soil is detectable along a gradient, with elevated levels of atmospheric nitric acid and ozone occurring in western areas of the park and high levels of atmospheric ammonia in eastern areas. This gradient is seasonal in nature in some areas; for example, in central park areas the lowest levels of reactive atmospheric nitrogen were recorded but nitric acid levels were higher in summer and nitrate levels were higher in winter. Higher levels of soil nitrogen led to decreased species richness in native forbs and indicated a potential shift to a less diverse vegetation community dominated by invasive annual grasses. This could create a feedback with fire cycles, as described previously, resulting indirectly in an altered fire cycle characterized by larger and more frequent fires. We do not have data that describe what the direct effects of increasing reactive atmospheric nitrogen in the soil are on *Y. brevifolia*. Nitrogen enrichment of soil could lead to a higher abundance of invasive grasses, which could drive fire cycles as described previously. However, the information we have regarding nitrogen enrichment does not indicate that it has negatively influenced population dynamics on a population or species scale.

Yucca jaegeriana

Altered Fire Regimes and Invasive Annual Grasses

Wildfires have not been historically common occurrences in the Mojave Desert (Brooks and Matchett 2006, p. 148), but they have increased in frequency in recent decades (Brooks *et al*. 2013, p. 2). Altered fire regimes and the prevalence of invasive annual grasses are closely coupled; therefore, we have combined the discussion of each into a single stressor discussion.

Because fires have not been historically common occurrences in southwestern deserts, native scrub vegetation communities in the Mojave Desert have not generally evolved or adapted to withstand effects from fire (Abella 2010, p. 1249). As a result, native plants in the Mojave Desert tend to be vulnerable to fire. However, over recent decades the frequency of fires in the Mojave Desert has increased, largely due to the proliferation of highly flammable invasive annual grasses that provide increased fuel loads for fires (Brooks *et al.* 2013, p. 2) as well as provide more continuity across open spaces between shrubs. *Yucca brevifolia* plants are not considered to be well-adapted to fire (Abella 2010, p. 1249).

Between 1980 and 2004, fires have predominantly occurred in the mid-elevation zone (Brooks and Matchett 2006, p. 153), which largely defines the range of *Yucca brevifolia* and *Y. jaegeriana*, and to a lesser degree lower elevation zones. Mid-elevation zones in particular experience flushes of invasive annual grasses, especially following years of above average precipitation, and this has increased the intensity of fires within the region (Brooks and Matchett 2006, p. 158). Within Joshua Tree National Park, California, for example, once-dominant native grasses have been replaced in many areas by more flammable invasive annual grasses, which bridge gaps between woody plants and as a result tend to carry fires across larger areas (Brooks and Matchett 2006, p. 162). As fires occur, more invasive grasses re-colonize and proliferate within the burned area, causing more frequent and increasingly larger fires. Within the park, records demonstrate that fires caused by lightning strike prior to 1965 tended to be small, not typically spreading more than tens of meters from the strike. More recent fires have measured in the thousands of acres, and this increase in fire size could cause significant shifts in vegetation communities in the park within a time frame of decades (Holmgren *et al.* 2009, p. 6).

This trend of increasing fire size has also been documented across the broader Mojave Desert. For example, the Southern Nevada Complex fires, which were started by lightning during the summer of 2005, burned almost 740,000 acres of Mojave and Great Basin Desert habitat in southeastern Nevada, southwestern Utah, and northeastern Arizona. This exceeded the total acres burned within the Mojave Desert within the entire preceding 25-year period (Brooks and Matchett 2006, p. 159). The spread of these fires was driven by unusually high amounts of invasive annual grasses as well as high winds. This resulted in a rapid rate of spread that consumed most grasses and herbaceous species and some shrubs and scattered trees (BLM 2011, p. S-5). In its final post-fire rehabilitation report, the Bureau of Land Management (BLM) noted that fire severity varied throughout the burned area, with 15 percent of the burned area experiencing either no vegetation mortality or very low mortality (0–5 percent), 71 percent of the burned area experiencing low-to-moderate vegetation mortality (6–60 percent), 13 percent of the burned area experiencing moderate vegetation mortality (61–85 percent), and 1 percent of the burned area experiencing high vegetation mortality (86–100 percent) (BLM 2011, p. 10).

While invasive grasses are linked most directly with increasing fire frequency, larger fires, and more severe fires in the southwest deserts, there have been instances in which native plant species have caused large fires as well. Following winters with unusually high amounts of precipitation, native perennial grasses and native annual forbs have been observed to flourish, with high amounts of above ground biomass filling the interstitial spaces between shrubs (McAuliffe 2016, p. 58; Esque *et al*. 2013, p. 2). During the summer months as plant material becomes drier, these species may also carry fire through the interstitial spaces between shrubs, having the same results as the presence of invasive grasses would have (Esque *et al*. 2013, p. 2). However, while this has been demonstrated as a potential source of more frequent, larger, and more sever fires, anticipated shifts in precipitation leading to less winter moisture may significantly diminish the potential for native species to flourish in this manner.

Direct effects to *Yucca jaegeriana* from fire include immediate mortality and reduced survivorship over time. For example, above normal precipitation in 1998 resulted in increased annual plant production that fueled many large fires in the Mojave Desert (DeFalco *et al.* 2010, p. 243). The mortality rate (from hereon, the term means the proportion of deaths in a population) for burned *Y. brevifolia* was approximately 80 percent compared to 26 percent for unburned plants. Plants that were shorter than 1 m in height were especially susceptible, as many died immediately after being burned. Young plants are most vulnerable to fire because they have their active meristems close to the ground. Overall survival for all size classes except for the tallest and oldest plants had declined to the same level by 2004. As noted by the researchers, the high mortality recorded in this study is consistent with high mortality documented in other studies, including 90 percent mortality 6 years after a fire in Joshua Tree National Park and 64–95 percent mortality at various sites between 1–47 years after fires in California portions of the Mojave and Sonoran Deserts. This study provides evidence that: (1) an abundance of invasive annual grasses may lead to larger fires than are historical; and (2) *Y. jaegeriana* plants are generally not well adapted to fires, with resulting high mortality rates, particularly those plants in smaller size classes. Other indirect effects to *Y. jaegeriana* from fire might include degraded seed bank, loss of aboveground vegetation that could serve as nurse plants to seedlings, and alteration in seed-caching rodent dynamics within *Y. jaegeriana* stands.

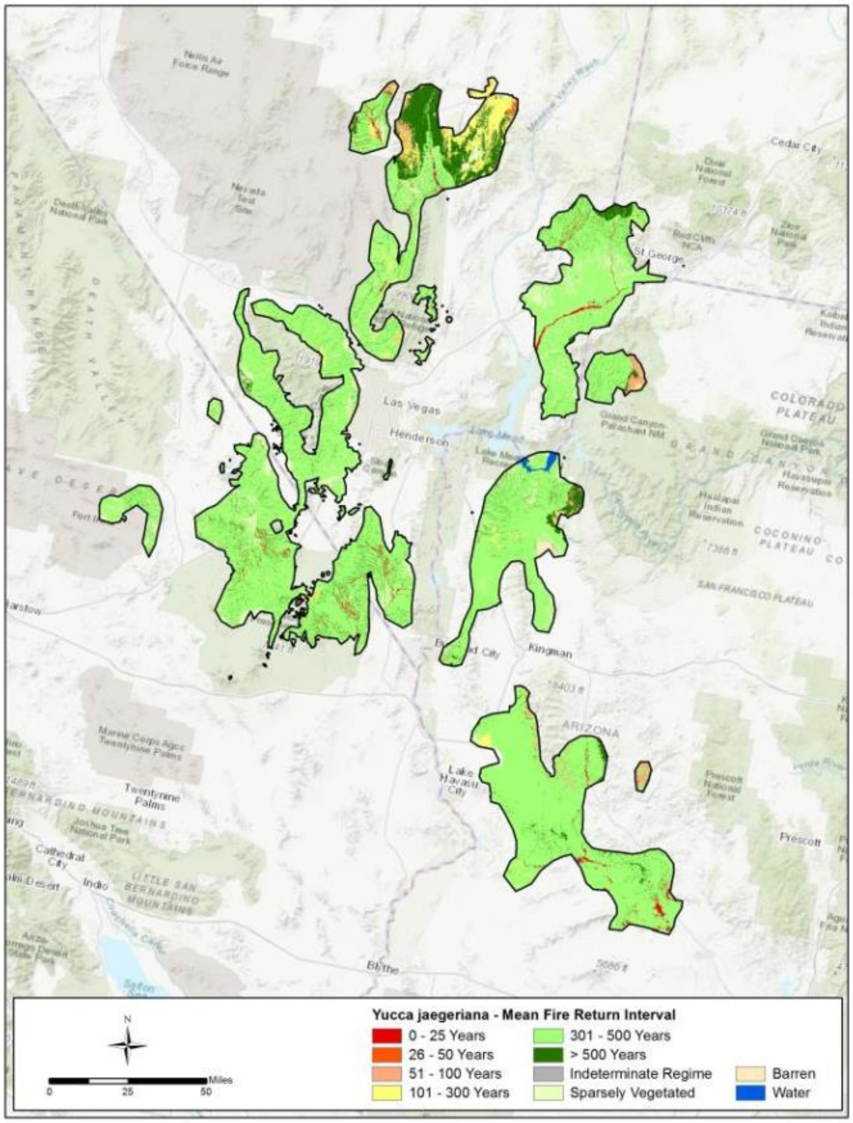


Figure 21: Estimated current mean fire return interval within *Yucca jaegeriana* population units

As illustrated in Figure 21, fire return intervals across *Yucca jaegeriana* population units are generally greater than 300–500 years, which is considered a long fire-return interval (Sugihara *et al*. 2006, p. 66). The effects to individual plants described above (i.e., direct mortality and diminished survival over time, degraded seed bank, and diminished germination and recruitment) could magnify to broader population and species level impacts as increasingly larger patches of individuals are directly or indirectly affected by fire. However, the majority of the *Y. jaegeriana* range currently experiences long fire-return intervals. Therefore, an increase in fire frequency may not be currently influencing the current condition of the *Y. jaegeriana* species at a population or species scale.

Climate Trends

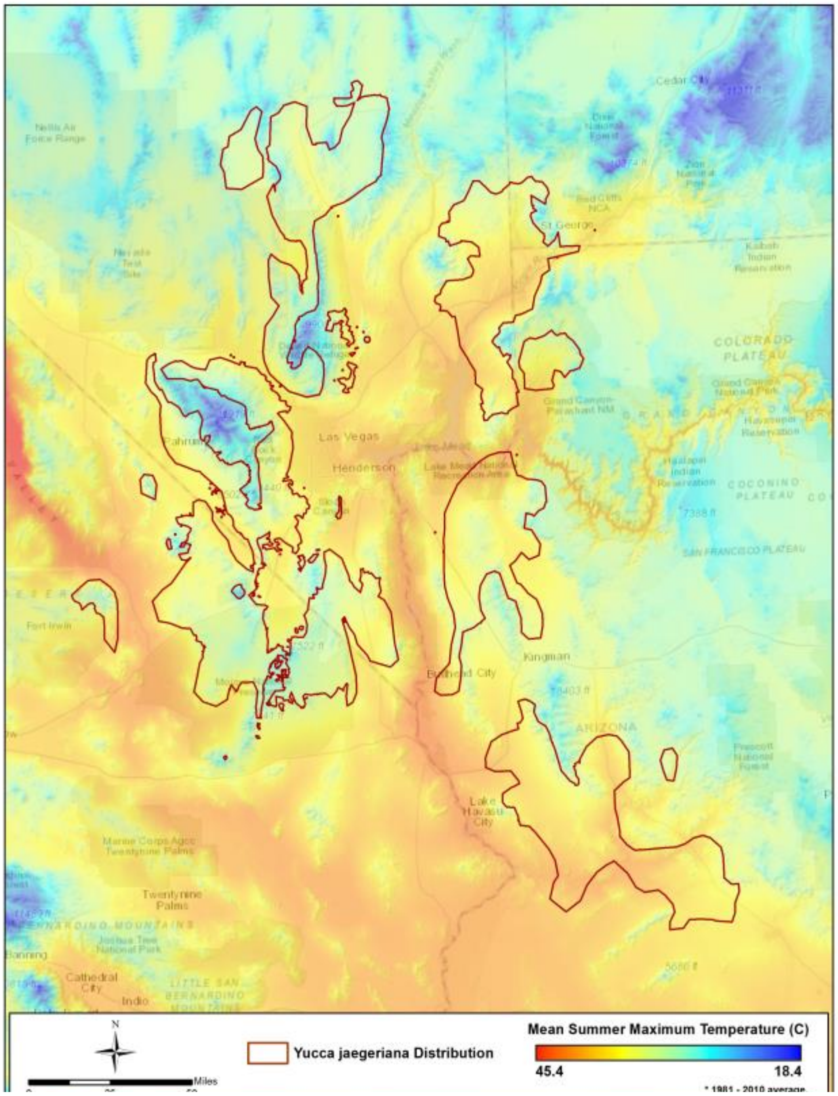


Figure 22: Mean summer temperatures within *Yucca jaegeriana* population units

Various changes in climate (e.g. increased temperatures, drought, precipitation timing) may have direct or indirect effects on species. These effects may be positive, neutral, or negative, and they may change over time, depending on the species and other relevant considerations, such as threats in combination and interactions of climate with other variables (for example, habitat fragmentation) (IPCC 2014, pp. 4–11). Changes in climate as a result of global warming may also influence or exacerbate other stressors on a species as well. There is scientific evidence for continued multi-decadal warming across the Earth's surface, with each of the previous three decades experiencing progressively warmer temperatures than any preceding decade since 1850 (IPCC 2014, entire). For the southwest U.S., temperatures have been increasing in past decades and since 1950 the region has experienced hotter temperatures than in any period during the past 600 years (Garfin *et al.* 2014, p. 464). Overall, 2016 was the hottest year ever recorded globally, and average temperatures have increased by approximately 1.0–1.2°C above pre-industrial levels (World Meteorological Organization 2017, p. 4; Polley *et al*. 2013, p. 493). The southwest U.S. is projected to be affected particularly severely by prolonged drought, fewer frost days, warmer temperatures, greater water demand by plants, and an increase in extreme weather events (Jepson *et al*. 2016, p. 49; Cook *et al*. 2015, entire; Archer and Predick 2008, pp. 23–24). Many of these phenomena may be influencing the current condition of *Yucca jaegeriana*.

As discussed previously in the Habitat section, *Yucca jaegeriana* does not generally occur in the hotter and dryer lower elevation areas of the Mojave Desert. Rowlands (1978, p. 179) posited that *Yucca jaegeriana* distribution across the Mojave Desert may be generally constrained by summer maximum temperature and winter minimum temperature. As illustrated in Figure 22, average summer maximum temperatures are generally warmer in the southern portion of the *Y. jaegeriana* range.

Due to similarities in life history and general ecology between *Yucca brevifolia* and *Y. jaegeriana*, effects of increasing maximum summer temperatures on *Y. jaegeriana* are assumed to be similar to those discussed previously for *Y. brevifolia*. Thus, *Y. jaegeriana* plants may be able to survive temperatures as high as 59ºC (Smith *et al*. 1983, p. 16). However, we do not have information about how warming or extreme high temperatures may influence *Y. jaegeriana* individuals. Increasing maximum summer temperatures may lead to reduced survivorship and decreased recruitment as evidenced by a model developed by Barrows and Murphy-Mariscal (2012, p. 35). However, the model also identified climate refugia where this species would persist, e.g., steep north facing slopes and higher elevations in the Park (Barrows 2018, pers. comm.). However, this model was applied to a small portion of the *Y. brevifolia* population and there is no documentation that increasing maximum summer temperature is influencing the current condition of *Y. jaegeriana* at a population or species scale.

Increasing minimum winter temperature

As discussed previously in the Species Needs section, and based on greenhouse experiments performed by Went (1957, p. 178), exposure to short periods of cold temperatures (below approximately 4ºC) may lead to optimal growth, reproduction, and recruitment for *Yucca brevifolia* and/or *Y. jaegeriana* individuals. However, we lack information to indicate whether these results apply to actual habitat conditions, and are unable to determine whether increasing minimum winter temperature has any effect on growth rate or other physiological parameters that may affect *Y. brevifolia* individuals. We are unable to determine which species (*Y. brevifolia* or *Y. jaegeriana*) was used in these greenhouse experiments. However, because life history, individual needs, population needs, species needs, and general ecology of *Y. brevifolia* and *Y. jaegeriana* are congruent we assume the effects and magnitude of effects would be the same for individuals of both species.

As illustrated in Figure 23, average winter minimum temperatures are generally warmer in the southern portions of *Yucca jaegeriana* populations and transition to generally cooler in northern portions. Rowlands (1978, p. 179) posited that *Y. jaegeriana* population distribution across the Mojave Desert may be generally constrained by summer maximum temperature and winter minimum temperature. If this constrained occurrence is considered in terms of population- and species-level effects, we could assume that the range of *Y. jaegeriana* could shift to more northern areas or to higher elevations where temperatures profiles are more accommodating to species needs. However, the information we have does not indicate that increasing minimum winter temperature has had any such effects on *Y. jaegeriana* abundance at a population or species scale.

Altered summer and cool season precipitation

As discussed previously in the Species Needs section, adequate amounts of precipitation throughout the year are likely to be important to *Yucca jaegeriana* individuals. Studies on *Y. jaegeriana* have indicated that summer precipitation may be important to individual plants, as wetter summers may result in larger germination events (Reynolds *et al.* 2012, p. 1652; Esque *et al.* 2015, p. 87). Research conducted in Piute Valley, Nevada, found that greatest seedling emergence for *Y. jaegeriana* occurred during spring and summer, when increased soil moisture was accompanied by warm soil temperatures, indicating adaptation to regular summer rainfall. *Y. brevifolia* seeds appear to germinate any time after a rain after seed shedding, which occurs in summer (Went 1948, p. 250). In general, more summer and cool season precipitation seems to result in more successful germination for individuals, leading to increased abundance within populations. Because life history, individual needs and general ecology of *Y. brevifolia* and *Y. jaegeriana* are congruent we assume the same would be true for *Y. jaegeriana*. Reynolds *et al.* (2012, p. 1652) also note that it is possible factors other than warm, wet conditions may be important for optimal emergence, but we do not have information to examine this possibility.

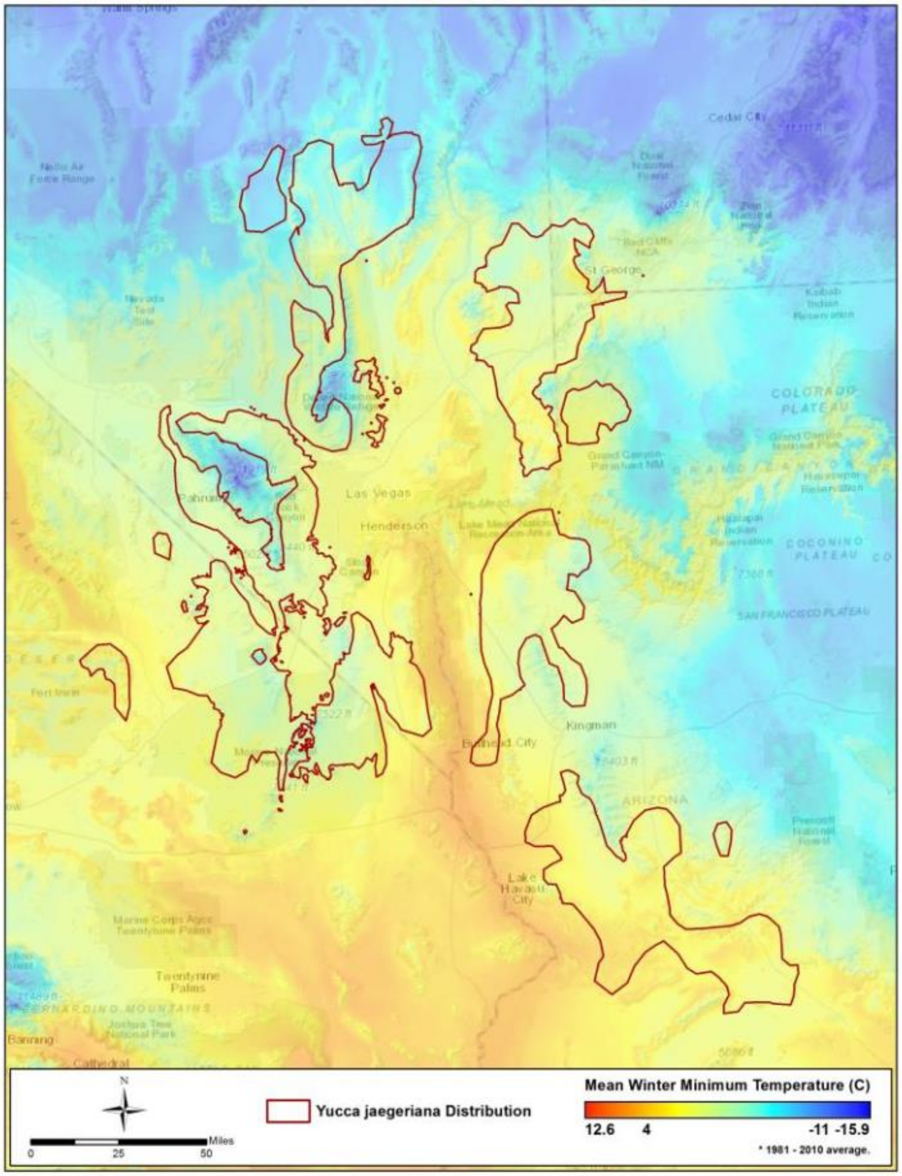


Figure 23: Mean Winter Temperature – *Yucca jaegeriana*. Based on Smith *et al.* 1983, lower limit threshold is -11 C. Based on Went (1957), optimal seedling growth occurs at 4 C.

As noted by Rowlands (1978, p. 179), *Yucca jaegeriana* seems to occur more in desert areas that receive over 20 percent of the mean annual precipitation during the summer, an amount greater than that for *Y. brevifolia* populations. Precipitation tends to be localized in nature across the range of *Y. jaegeriana* and we do not have specific information about how historic precipitation patterns have affected the current condition of the species. As illustrated in Figure 5, there is a general trend of less precipitation in the more western *Y. jaegeriana* population areas. Based on this pattern and on the studies cited above, it is possible that germination rates could vary within *Y. jaegeriana* population units along a precipitation gradient. However, we have no information about whether a critical threshold exists for the influence that precipitation may have on germination and recruitment. Because germination and recruitment at some level of success is likely occurring throughout the range of *Y. jaegeriana*, and because we lack information that would indicate otherwise, we are unable to determine whether altered summer and cool season precipitation patterns are influencing the current condition of *Y. jaegeriana* at a population or species scale. If germination and recruitment of individuals is being diminished as precipitation pattern and abundance is altered, the loss of individuals could have detrimental effects at the population- or species-scale by reducing abundance of *Y. jaegeriana* at each scale.

Prolonged periods of drought

Climate change impacts in the southwest U.S. to date have included increased frequency and intensity of extreme weather events such as drought (Garfin *et al.* 2014, p. 464; Archer and Predick 2008, pp. 23–24). Additionally, the severity of drought events could be intensified due to consistently high temperatures in conjunction with low precipitation (Archer and Predick 2008, p. 24).

Drought has been demonstrated to potentially influence decadal demography in *Yucca jaegeriana* by increasing herbivory of young (less than 25 cm tall) plants (Esque *et al.* 2015, p. 87). It has also been demonstrated to potentially influence demography in *Y. brevifolia* by reducing survival rates in juvenile individuals (less than 1 m tall; Defalco *et al*. 2010, p. 246), and we assume the effects and magnitude of effects of prolonged drought would be the same for *Y. jaegeriana*. Periods of drought may generally affect individuals by reducing the amount of water available to plants at times when adequate rainfall would lead to optimal germination and recruitment. Reduced recruitment over time could lead to contraction of populations. Prolonged, intense droughts within the broader range of *Y. jaegeriana* occurred during the 1930s Dust Bowl, 1950s, and 1990s–2000s, with dramatic impacts on the landscape that included native vegetation mortality events (Notaro *et al.* 2012, p. 1365). However, considering the limited scope of these studies and historical drought periods experienced within the range of the species, based on the available information there is no indication that periods of prolonged drought are currently impacting *Y. jaegeriana* at a population or species scale.

CO_2 enrichment

The greenhouse effect is the result of elevated atmospheric levels of CO_2, the effects of which may stimulate plant growth and reduce the negative effects of drying in a warmer climate via increasing plant water use efficiency (Polley *et al*. 2013, p. 498). However, this effect may be mediated by other conditions related to increasing temperatures, particularly soil water availability. Net effects could be numerous and varied, including modifications to forage quality and quantity, as well as shifts in general species distributions. For example, Smith *et al*. (2000,

p. 81) demonstrated that new shoot production of dominant perennial shrubs doubled following a 50 percent increase in atmospheric CO_2 in a high rainfall year, while elevated CO_2 did not increase perennial shrub production in a drought year. However, we do not have species-specific information to indicate how elevated atmospheric CO_2 has affected *Yucca jaegeriana* populations. As a result, we do not consider CO_2 enrichment to be a stressor driving the current condition of *Y. jaegeriana* at a population or species scale.

Habitat Loss

The loss of habitat is occurring in varying degrees across the range of *Y. jaegeriana*. Because habitat loss may result in the permanent removal of plant cover and loss of soil structure, it can negatively affect the landscape condition for current *Y. jaegeriana* populations and may constrain future range expansion. The discussion here presents presumed stressors and how each could potentially influence *Y. jaegeriana* population dynamics, as well as land management factors that could potentially alleviate or exacerbate these effects. Contributors to large-scale habitat loss across the range of *Y. jaegeriana* may include urban expansion and development, military installation expansion and training activities, renewable energy development, grazing, and OHV use.

Urban expansion and development

The YUJA North and YUJA East populations occupy mostly undeveloped habitat, with development not representing a threat to either population. Approximately 0.7 percent of *Yucca jaegeriana* range is occupied by urban or metropolitan development. In the YUJA Central population, the urban growth and expansion of Las Vegas, Henderson, and Pahrump, Nevada, has likely removed a substantial amount of habitat and individual *Y. jaegeriana* plants over preceding decades. In spite of this, the total area lost within the YUJA Central population to urban expansion still comprises a small proportion of overall *Y. jaegeriana* current mapped distribution. The YUJA Central population may contain some of the densest areas of *Y. jaegeriana* across the three populations (Rowlands 1978, p. 74). There are also Federal, State and local laws and ordinances in place that protect *Y. jaegeriana* from harvesting to some degree (Table 3). Therefore, habitat loss due to urban development may result in the loss of individuals across the landscape, but it is not likely to influence the current condition of *Y. brevifolia* at a population- or species-scale.

Military activities

A small proportion of the YUJA North population overlaps with Nellis Air Force Base, and a small proportion of the YUJA Central population extends into the Fort Irwin National Training Center. Development, land use changes, and training activities within military installations can degrade and potentially remove *Yucca jaegeriana* habitat.

Approximately 8.5 percent of the *Yucca jaegeriana* current mapped distribution occurs on military lands (Table 1). Based on available information, there is no indication that military activities have influenced the current condition of *Y. jaegeriana* at a population or species scale. Additionally, incorporation of INRMP's on the DoD installations may provide management and conservation benefit to plants as identified above (see pages 49–51).

Renewable energy development

Renewable energy development has degraded *Yucca jaegeriana* habitat and resulted in habitat loss within the range of the species. Examples of projects include solar, wind, and geothermal development. However, it is unknown how this loss of habitat has affected current populations, and because the total area of habitat already lost to renewable energy development comprises a relatively small proportion of the *Y. jaegeriana* range there continue to be large expanses of habitat and potential refugia available. Within the range of *Y. jaegeriana*, approximately 1.9 percent of current mapped distribution has been developed for renewable energy. Because of this small proportion, loss of habitat due to renewable energy development is unlikely to be influencing the current condition of *Y. jaegeriana* at a population or species scale.

Grazing

While grazing allotments overlap a relatively large proportion of the *Yucca jaegeriana* current mapped distribution (approximately 53.8 percent), many of these allotments are not actively being grazed. Effects from grazing on *Y. jaegeriana* individual plants include impacts from herbivory, trampling of young plants, or loss of soil structure. Based on Rowland's surveys in 1978 (p. 82) intensive grazing had depleted the perennial grasses in the YUJA East population and he suggested that cactus species may now play a more important role in the characterization of the vegetation in this population. However, because *Y. jaegeriana* has remained persistent on the landscape in spite of grazing effects, we assume that livestock use is a low level stressor that does not impact the current condition of *Y. jaegeriana* at the population or species scale.

Off Highway Vehicle Use

Authorized and unauthorized OHV use likely occurs throughout a large proportion of the *Yucca jaegeriana* range. Where use is most intense, disturbance and habitat loss can be severe, with vegetation largely removed and soil structure compromised. This could affect *Y. jaegeriana* by degrading the seed bank and removing nurse plants that benefit germination. However, over broader areas OHV use is more generally diffuse in nature, resulting in fragmented effects that do not result in complete habitat loss. Therefore, while some *Y. jaegeriana* individuals are being impacted by OHVs, it is unlikely that OHV use is impacting the current condition of *Y. jaegeriana* at the population or species scale.

Herbivory

Herbivory of *Yucca jaegeriana* leaves and periderm by desert woodrats, black-tailed jackrabbits, and other granivores has been documented (Sanford and Huntly 2009, p. 167; Cornett 2017, p. 9), with direct mortality observed in adult and in particular seedling life stages (Esque *et al.* 2015, p. 87). Herbivory pressure from various granivores, working in tandem with the typical low germinability of *Y. jaegeriana* seeds in the soil, has been linked with reduced seedling germination and establishment (Reynolds *et al.* 2012, p. 1652). Esque *et al.* (2015, p. 85) found that herbivory of *Y. brevifolia* plants by black-tailed jackrabbits in years one and two of their study caused 45 percent and 31 percent mortality, respectively. Because life history, individual needs and general ecology of *Y. brevifolia* and *Y. jaegeriana* are congruent we assume these same effects would be true for *Y. jaegeriana*. Rodent, rabbit, hare, or mule deer herbivory was recorded within sites monitored across the range of *Y. jaegeriana* and led to varying degrees of individual juvenile plant mortality (Cornett 2017, Table 1). However, there is no information to indicate that herbivory has negatively influenced *Y. jaegeriana* at a population or species scale.

Overutilization

Overutilization of *Yucca jaegeriana* (such as illegal harvesting of plants) is not likely a significant stressor to the species, as no published research is available to inform otherwise. There are state and local regulations that prohibit the harvesting of *Y. jaegeriana* plants throughout portions of the range. In California, harvesting of *Y. jaegeriana* plants is restricted by the California Desert Native Plant Act (CLI 1981, entire). In California, Nevada, and Arizona harvesting on BLM land requires a permit and tag (NDF undated, p. 1). Harvest of plants on Forest Service and NPS lands is prohibited (Forest Service undated, p. 1; ECFR 2018, p. 1), and harvesting on other public and private land may be regulated by local ordinances (see Table 3). In Arizona, *Y. jaegeriana* plants (identified as a subspecies) are considered salvage protected restricted native plants, and plants can only be collected with a permit (ADOA 2015, entire). The state of Utah does not currently have any prohibitions or protections against the harvest of *Y. jaegeriana* plants.

Nitrogen Enrichment (Air Pollution)

Allen *et al*. (2009, p. 13) demonstrated that in Joshua Tree National Park, reactive atmospheric nitrogen from urban areas that becomes deposited in the soil was detected along a gradient, with elevated levels of atmospheric nitric acid and ozone occurring in western areas of the park and high levels of atmospheric ammonia in eastern areas. This gradient is seasonal in nature in some areas; for example, in central park areas the lowest levels of reactive atmospheric nitrogen were recorded but nitric acid levels were higher in summer and nitrate levels were higher in winter. Higher levels of soil nitrogen led to decreased species richness in native forbs and indicated a potential shift to a less diverse vegetation community dominated by invasive annual grasses. This could create a feedback with fire cycles, as described previously, resulting indirectly in an altered fire cycle characterized by larger and more frequent fires. We do not have data that describe what the direct effects of increasing reactive atmospheric nitrogen in the soil are on *Yucca jaegeriana*. Nitrogen enrichment of soil could lead to a higher abundance of invasive grasses, which could drive fire cycles as described previously. However, the information we have regarding nitrogen enrichment does not indicate that it has negatively influenced population dynamics on a population or species scale.

Populations – Current Condition, 3 R's

Resiliency encompasses population-specific attributes that increase long-term persistence in the face of disturbance or stochastic events. Resiliency can also address related issues regarding whether a species has responded favorably to an elimination or management of threats and recovery of ecologically effective populations (Wolf *et al*. 2015, p. 205). A species with a larger suitable habitat area, a high number of large populations, sufficient gene flow, and more intact ecosystems can have a lower extinction risk (Wolf *et al*. 2015, p. 204) and result in more resilient populations.

Ideally, to assess Joshua tree population resilience, we would evaluate population resiliency in terms of population size, population growth rate, and other demographic variables but those data are not available. As a result, we will use habitat elements to evaluate population resiliency. These habitat elements include the amount of the mapped distribution managed or conserved, and the number of ecological settings or ecoregions within each population (see Table 2) to serve as a proxy in determining population resiliency. In our evaluation of these habitat elements, we assume that larger, less disturbed (management/conservation potential) habitat areas within a diversity of ecological settings within the species' current mapped distribution, results in more intact ecosystems and would provide for long-term persistence in the face of disturbance and stochastic events. Species occupying habitats characterized as such would most likely have populations that are more resilient to increased variability or changes in resource needs under a variety of conditions (Noss *et al*. 1997, p. 6).

Suitable Habitat Area Determinations

To determine the amount of habitat available for *Yucca brevifolia* and *Y. jaegeriana*, we evaluated the species' habitat variables in the population areas mapped in Figure 4. We did this by identifying the percent of the currently known Joshua tree mapped distribution that supports individual resource needs (soils, seed bank, nurse plants, etc.) within each regional population. We used the National Land Cover Database (NLCD), which represents a decade of consistently produced land cover to identify suitable habitat for each population. We included areas that may support the resource functions needed to ensure persistent populations and excluded those that do not (Table 4).

Management and/or conservation potential

To evaluate the management and/or conservation potential we assumed that Joshua trees located within NPS units, BLM's Areas of Critical Environmental Concern (ACEC) and National Conservation Lands [Formerly known as the National Landscape Conservation System (NLCS)], and other wilderness designations had more management/conservation potential than lands occurring outside such designated areas. For example, ACEC's are federally designated areas where special management attention is provided through federal regulation to protect important historical, cultural, and scenic values, or other natural resources. NLCS designated lands conserve special features and offer opportunities for hunting, solitude, wildlife viewing, fishing, history exploration, scientific research, and a wide range of traditional uses that are also managed under federal regulation. NPS lands are managed for natural and cultural resource conservation and outdoor recreation. Therefore, we assumed these management/conservation areas generally limit large-scale habitat disturbances and provide more intact ecosystems to support more resilient local populations of Joshua trees.

Table 4: NLCD Landcover Classifications included and excluded from current mapped distribution

Cover Type	Supports Joshua Tree Resource Needs
Deciduous Forest	Yes
Developed, Open Space	Yes
Evergreen Forest	Yes

Cover Type	Supports Joshua Tree Resource Needs
Grassland/Herbaceous	Yes
Mixed Forest	Yes
Shrub/Scrub	Yes
Barren Land	No
Cultivated Crops	No
Developed, High Intensity	No
Developed, Low Intensity	No
Developed, Medium Intensity	No
Herbaceous Wetlands	No
Open Water	No
Pasture/Hay	No
Woody Wetlands	No

Ecoregions

We used the Level IV EPA ecological region (ecoregions) units, derived from Omernik (1987, entire), to identify unique areas of geology, landforms, soils, vegetation, climate, and hydrology characteristics (Figures 7 and 9; Omernik and Griffith 2014, p. 1254). These ecoregions represent the number of ecological settings across the population and could be an indicator of genetic diversity, ecological interactions, and the species ability to adapt to change (Carroll *et al*. 2010, entire). We overlaid the Joshua tree mapped distribution (Figure 4) with ecoregion units to quantify the number of unique ecoregions in each Joshua tree population. We assumed the higher the number of ecoregions supported the more diverse the population with a higher capacity to adapt to change.

Yucca brevifolia

A discussion of the current condition of each *Yucca brevifolia* population along with summary tables is presented below. We used the habitat elements to assist in determining the current condition of each population. Populations with an abundance of habitat elements are assumed to have the capacity to withstand stochastic disturbance events, that is, to rebound from relatively extreme numerical lows that relates to the resilience of each population.
YUBR South: This *Yucca brevifolia* population is distributed throughout a 3.7 million-acre (1.5 million ha) area with high variability in densities and a relatively large amount of private lands (51 percent) and existing urban development in relation to the YUBR North population. Within the current mapped distribution, 87.4 percent of the habitat is suitable, 32.7 percent has management/conservation potential, and 13 ecoregions are represented (Table 5). This population mainly occurs in desert basin regions within the western Mojave Desert characteristic of low summer rainfall (less than 10 percent of the annual average). A few areas within this population encompass the higher elevation transitions between the desert and mountains, which accounts for the large variation in average winter minimum temperatures [-5.7°C to 4.8°C (22° to 41° F)].

Table 5: *Yucca brevifolia* Ecoregions within mapped suitable habitat.
Highlighted cells represent ecoregions common to both populations.

***Yucca brevifolia* Ecoregions**	**YUBR South**	**YUBR North**
Amargosa Desert		✓
Arid Montane Slopes	✓	
Eastern Mojave Basins	✓	✓
Eastern Mojave Low Ranges and Arid Footslopes	✓	✓
Eastern Mojave Mountain Woodland and Shrubland		✓
Eastern Sierra Great Basin Slopes	✓	✓
Eastern Sierra Mojavean Slopes	✓	✓
Lahontan and Tonopah Playas		✓
Mojave Lava Fields	✓	
Northern Transverse Range	✓	
Sierra Nevada-Influenced Ranges		✓
Southern California Lower Montane Shrub and Woodland	✓	
Southern California Montane Conifer Forest	✓	
Tehachapi Foothills	✓	
Tehachapi Mountains	✓	
Tonopah Basin		✓
Tonopah Sagebrush Foothills		✓
Tonopah Uplands		✓
Upper Owens Valley		✓
Western Mojave Basins	✓	✓
Western Mojave Low Ranges and Arid Footslopes	✓	✓
Western Mojave Mountain Woodland and Shrubland		✓

We have little information on the current numbers, densities, and age classes of existing Joshua tree stands across the YUBR South population region outside of NPS lands. On NPS lands within the Mojave Desert, *Yucca brevifolia* and *Y. jaegeriana* demographic structure and plant density was evaluated from 2007 to 2010 in occupied areas using stratified random plots by Esque *et al*. (2010, entire). Results indicate plant density in Joshua Tree National Park is highly variable but had the highest mean density with 95.2 trees/ha across NPS units sampled (Table 6) (Esque *et al*. 2010, p. 10). Esque *et al*. (2010, pp 10–11) also found the size distribution structure of both *Y. brevifolia* and *Y. jaegeriana* are similar to other long-lived plants with a large numbers of small plants [<1 m (<3.3 ft)], moderate numbers of plants between 1 and 5 m (3.3 and 16.4 ft), and reduced numbers of plants taller than 5 m (16.4 ft). Comprehensive *Y. brevifolia* monitoring of density, mortality, and survivorship at Joshua Tree National Park by park staff was initiated in 2016. Preliminary results indicate a wide range of density and mortality rates across plots and recent recruitment events. These plots will be monitored into the future as funding and staffing allows and will provide much needed demographic data. The surveys conducted by park staff within Joshua Tree National Park have also found that *Y. brevifolia* occurs south of what was thought to be the plant's southern extent (NPS 2017, p. 5).

Within the mapped distribution of this population, there are approximately 1.7 million acres (694,086 ha) of federal lands administered by the NPS, BLM, Forest Service, and DoD (Table 1). This population also includes several California State and County parks and preserves. Management and monitoring activities in Joshua Tree National Park include Joshua tree demographic monitoring as described above and invasive species management.

Table 6: National Park units, mean density, and range of the number of Joshua trees found on plots in the Mojave Desert 2007 and 2008. *Adapted from Esque et al., 2010, Table 1.*

Park Unit	Mean Density of Joshua Trees/ha	Mean Density of Joshua Trees/ac	Density Range/ha	Density Range/ac	Species	Population
Joshua Tree National Park	95.2	235	4 – 112	10 – 277	*Yucca brevifolia*	YUBR South
Death Valley National Park	62	153	4 – 340	10 – 840	*Yucca brevifolia*	YUBR North
Mojave National Preserve	83.6	206	4 – 252	10 – 622	*Yucca jaegeriana*	YUJA Central
Lake Mead National Recreation Area	30.8	76	8 – 84	20 – 207	*Yucca jaegeriana*	YUJA North
Grand Canyon/Parashant National Monument	37.2	92	4 – 128	10 – 316	*Yucca jaegeriana*	YUJA North

YUBR North: This *Yucca brevifolia* population is distributed throughout a 1.9 million-acre (800,402 ha) area with 97 percent of distribution occurring on federal lands (Table 1) managed by the NPS, BLM, Forest Service, and DoD. Within the current mapped distribution, 98.2 percent of the area is suitable habitat, 37.3 percent has management/conservation potential, and 15 ecoregions are represented (Table 5). These northern *Y. brevifolia* populations transition from the dry, desert regions of the Mojave Desert to a more temperate, intermountain desert region typical of the Great Basin Desert. The amount of the average annual precipitation falling during summer varies between 10 and 25 percent and mean winter temperatures range from -8.1°C to 3.6°C (17 to 38°F).

Similar to YUBR South, we have little information on the current numbers, densities, and age classes of existing Joshua tree stands across the YUBR North population region. Based on the short-term demographic research described above by Esque *et al.* (2010, p. 11), density in plots surveyed in Death Valley National Park is highly variable with ranges between 4 and 340 trees per ha with a mean density of 62 trees/ha (see Table 6), which represents a higher number of trees found in individual plots compared to Joshua Tree National Park, but with a lower average density.

YUBR South

<table>
<tr><td>Demographics:
• 4–112 trees per ha (NPS 2017; Esque <i>et al</i>. 2010)</td><td>Distribution:
• Ecological Setting: Dry, semi-desert/desert; coastal ranges and woodlands</td><td>Habitat Elements
• 3,255,088 ac/1,317,288 ha (87.4 percent)-suitable habitat
• 32.7 percent management/conservation potential
• 13 ecoregions represented</td></tr>
<tr><td colspan="3">Current Population-wide Unknowns:
• Status of pollinators
• Number of reproducing individuals
• Seedling survival/recruitment rate
• Juvenile survival/recruitment rate
• Adult Survival
• Age (size) distribution
• Population numbers</td></tr>
</table>

Research by Esque *et al.* (2015, p. 87–88) measuring growth and survivorship of pre-reproductive *Yucca brevifolia* from 1989 to 2011 at Yucca Flat, Nevada, on the Nevada National Security Site, found a strong relationship between the height of *Y. brevifolia* and plant survival. Surviving plants experienced low annual mortality, 2.5 percent. Survival of the individuals in the study plot was 19 percent over 22 years. Plants less than 25 cm (10 in) in height had lower life expectancy, while 30-year-old plants had not yet reproduced, and only one of the plants surveyed during the 22 year period died solely as a result of drought.

<table>
<tr><th colspan="3">YUBR North</th></tr>
<tr><td>Demographics:
• 4 to 340 trees per ha (Esque <i>et al</i>. 2010)</td><td>Distribution:
• Ecological Setting: Temperate, high elevation deserts</td><td>Habitat Elements
• 1,941,701 ac/785,779 ha (98.2 percent) suitable habitat
• 37.3 percent management/conservation potential
• 15 ecoregions represented</td></tr>
<tr><td colspan="3">Current Population-wide Unknowns:
• Status of pollinators
• Number of reproducing individuals
• Juvenile survival/recruitment rate
• Adult Survival
• Age (size) distribution
• Population numbers and densities</td></tr>
</table>

Yucca brevifolia Current condition

Yucca brevifolia is currently distributed across a 5.7 million-acre (2.3 million ha) area in two regional populations (YUBR South and YUBR North) mostly across the western Mojave Desert. Approximately 5.1 million acres (2.1 million ha) of this area is able to support individual habitat resource needs for this species. The southern population (YUBR South) has more suitable habitat, a smaller percent of habitat that has management/conservation potential, and less ecological diversity (i.e., two fewer ecoregions) than the northern population (Figure 24). There is a higher percentage of summer rainfall and lower winter temperatures in the northern population, which may support more frequent recruitment events and higher survival of juvenile plants. However, we consider that currently both populations have a high capacity to withstand or recover from stochastic disturbance events due to the large distribution, ecological diversity, and large acreages within management/conservation areas containing intact habitat for the species.

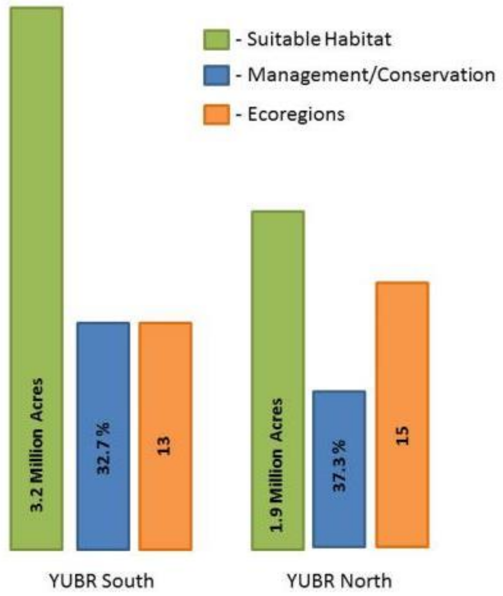


Figure 24: Habitat Elements, Yucca brevifolia

Although we do not have population estimates, we consider it reasonable to assume redundancy is high within YUBR South and YUBR North as these regional populations are spread across very large, intact habitat areas that support resource needs. There is no evidence to support recent (post-Holocene) population size reductions based on genetic information (Smith *et al*. 2011, p. 10) or to indicate a range contraction over the last 40 years based on distribution mapping (Rowlands 1978, p. 52). Additionally, plants are located primarily on federal lands with less occurrence of anthropogenic development. Potential adverse impacts to the species are spread across a 5.6 million-acre area so it is not likely that catastrophic events, such as wildfire, would lead to the death of every individual in either regional population.

Representation, as measured by the ecological diversity of habitats *Yucca brevifolia* inhabits, is likely high as the two regional populations occupy highly diverse areas within the Mojave and Great Basin Deserts that encompass differences in elevation, soil type, temperature, rainfall, and vegetation communities (i.e., Ecoregions). Also, *Y. brevifolia* exhibit differences in physical stature and branching arrangement within and across populations. For example, vegetative traits, such as leaf length and height to first branching, vary widely among individuals and across populations (Godsoe *et al.* 2009, p. 598) and seed and fruit production appears to be highly variable (Borchert and DeFalco 2016, p. 833) across years and sites. This information suggests *Y. brevifolia* has a high degree of flexibility and can adapt to changing environmental conditions, which may provide the species the capacity to withstand extreme environmental events resulting in a high degree of species representation.

Yucca jaegeriana

A discussion of the current condition of each *Yucca jaegeriana* population along with summary tables is presented to evaluate population-level resiliency.

YUJA Central: This *Yucca jaegeriana* population is distributed throughout a 3 million-acre area (1.2 million ha) and is characterized by the hills and low mountain ranges that rise above the basins within the eastern Mojave Desert, with northern areas more characteristic of Great Basin desert vegetation at higher elevations. Within the current mapped distribution, 97.6 percent of the area is suitable habitat, 55.3 percent of the area has management/conservation potential, and

10 ecoregions are represented in this population (Table 7). The amount of the average annual precipitation [102.3 mm to 491.6 mm (4.03 in to 19.35 in)] that falls during summer varies between 25 and 40 percent and mean winter temperatures range from -5.3 to 5.9°C (22 to 43ºF). Within the mapped distribution of this population, there are approximately 2.6 million acres (1 million ha) of federal lands administered by several agencies including: the NPS, BLM, Forest Service, and DoD (Table 1).

Similar to *Yucca brevifolia* populations, we have little information on the current numbers, densities, and age classes of existing Joshua tree stands across the YUJA Central population region. Short-term demographic monitoring in NPS units by Esque *et al.* (2010, p. 11) indicated plant density is highly variable in the Mojave National Preserve (4 to 252 trees/ha) and Lake Mead National Recreation Area (8 to 84 trees/ha) (Table 6). The population size distribution for *Y. jaegeriana* is the same as what is reported for *Y. brevifolia* [Esque *et al*. (2010, p. 11) (see section YUBR South above].

YUJA Central		
Demographics: • 4 to 252 trees per ha (Esque *et al*., 2010)	**Distribution:** • Ecological Setting: Arid, mid to high elevation eastern Mojave Desert's low hills, mountain ranges, and basins	**Habitat Elements** • 2,997,787 ac/1,213,162 ha (97.6) percent suitable habitat • 55.3 percent management/conservation potential 10 ecoregions represented
Current Population-wide Unknowns: • Status of pollinators • Number of reproducing individuals • Seedling survival/recruitment rate • Juvenile survival/recruitment rate • Adult Survival • Age (size) distribution • Population numbers and densities		

<u>YUJA North</u>: This *Yucca jaegeriana* population is distributed throughout a 2 million-acre area with ecoregions similar to those of YUJA Central but with more of a Great Basin Desert influence. Within the current mapped distribution, 1.6 percent of the area is unsuitable habitat, 57.8 percent of the area has management/conservation potential, and 14 ecoregions are represented in this population (Table 7). The amount of the average annual precipitation [109.9 mm and 441.7 mm (4.33 in and 17.39 in)] that falls during summer varies between 20 and 30 percent and mean winter temperatures range from -6.5–4.2°C (20–40°F). Most of the area within the current mapped distribution of this population (96 percent) is on federal lands administered by several agencies including: the Service, the NPS, BLM, and DoD (Table 1).

Table 7: *Yucca jaegeriana* Ecoregions.

Green highlight indicates overlap between YUJA Central and YUJA North, blue highlight indicates overlap between YUJA North and the Hybrid Zone, gray highlight indicates overlap between all three YUJA populations.

Yucca jaegeriana Ecoregions	YUJA Central	YUJA North	YUJA East	Hybrid Zone
Amargosa Desert	✓			
Arid Valleys and Canyonlands	✓	✓		
Arizona Strip Plateaus		✓		
Arizona Upland/Eastern Sonoran Basins			✓	
Arizona Upland/Eastern Sonoran Mountains			✓	
Carbonate Sagebrush Valleys		✓		✓
Carbonate Woodland Zone		✓		✓
Central Sonoran/Colorado Desert Basins			✓	
Eastern Mojave Basins	✓	✓	✓	
Eastern Mojave Low Ranges and Arid Footslopes	✓	✓	✓	
Eastern Mojave Mountain Woodland and Shrubland	✓	✓		
Hualapai/Coconino Woodlands	✓			
Lower Mogollon Transition			✓	
Mojave Lava Fields	✓			
Mojave Playas	✓	✓		
Shadscale-Dominated Saline Basins		✓		
Tonopah Basin		✓		✓
Tonopah Sagebrush Foothills		✓		✓
Tonopah Uplands		✓		
Virgin/Shivwits Woodland		✓		
Western Mojave Basins	✓	☐		
Western Mojave Low Ranges and Arid Footslopes	✓	☐		
Woodland- and Shrub-Covered Low Mountains		✓		

Similar to YUJA Central populations, we have little information on the current numbers, densities, and age classes of existing Joshua tree stands across the YUJA North population region. Short-term demographic research by Esque *et al*. (2010, p. 11) indicates plant density in the Grand Canyon/Parashant National Monument is highly variable with ranges between 4–128 trees per ha. The population size distribution for *Y. jaegeriana* on these lands in northwestern Arizona is the same as what is reported for *Y. brevifolia* (Esque *et al*. 2010, p. 11) (see section YUBR South above). The size class distribution on BLM lands in southwestern Utah also includes a high proportion of relatively young trees, indicating recent establishment and successful recruitment (Gilliland *et al.* 2006, p. 206). Age calculations were derived for larger individuals using annual growth measurements, and approximately 50 percent of sampled individuals were at least 89 years old, and 5 percent of sampled individuals reached the oldest age of 383 years.

Gilliland's sample had the majority of the reproductive trees estimated to be about 138 years old (Gilliland *et al.* 2006, p. 206). High survival of all monitored plants was documented over a 14 year period with overall annual survival was over 90 percent (Gilliland *et al*. 2006, p. 206).

YUJA North		
Abundance and Demographics: • 4 to 128 trees per ha (Esque *et al*. 2010)	**Distribution:** • Ecological Setting: Less arid transition areas between the Great Basin and the eastern Mojave Desert	**Habitat Elements** • 2,035,901 ac/ 823,901 ha (98.4 percent) suitable habitat • 57.8 percent management/conservation potential 14 ecoregions represented
Current Population-wide Unknowns: • Status of pollinators • Number of reproducing individuals • Seedling survival/recruitment rate • Juvenile survival/recruitment rate • Adult Survival • Age (size) distribution • Population numbers and densities		

<u>YUJA East</u>: This *Yucca jaegeriana* population is distributed throughout a 1.3 million-acre area mostly within the Sonoran Desert. Within the current mapped distribution, 99.3 percent of area is suitable habitat, 23.5 percent of the area has management/conservation potential, and six ecoregions are represented in this population (Table 7). This population experiences more of the annual rainfall [145.3–443.7 mm (5.72–17.47 in)] occurring in summer months (more than 35 percent of annual rainfall). Mean winter temperatures are generally higher than those in the Mojave Desert and range from -1–5.5°C (30–42°F). Based on our current mapped distribution, this population may be the most isolated of all *Y. jaegeriana* populations due to physical distance from the other two populations, major highways, and urban development. We have no information on the current numbers, densities, and age classes of existing Joshua tree stands across the YUJA East population region.

The YUJA East population includes approximately 862,656 ac (349,104 ha) of federal lands that span several BLM Field Offices and the BOR's Alamo Lake unit (Table 1). Management and monitoring activities on these lands include rangeland heath evaluations used mostly to evaluate range condition and livestock utilization.

YUJA East		
Abundance and Demographics: • Unknown	**Distribution:** • Ecological Setting: More arid, hotter Arizona upland,	**Habitat Elements** • 1,280,820 ac/ 518,330 ha (99.3 percent) suitable habitat

<table>
<tr><td></td><td>Sonoran Desert mountains and basins</td><td>• 23.5 percent management/conservation potential
• 6 ecoregions represented</td></tr>
<tr><td colspan="3">Current Population-wide Unknowns:
• Current densities
• Status of pollinators
• Number of reproducing individuals
• Seedling survival/recruitment rate
• Juvenile survival/recruitment rate
• Adult Survival
• Age (size) distribution
• Population numbers and current densities</td></tr>
</table>

Yucca jaegeriana Current Condition

Yucca jaegeriana is distributed across a 6.4 million-acre area (2.6 million ha) in three regional populations across the eastern Mojave Desert, small portion of the southern Great Basin Desert and western Sonoran Desert. Approximately, 6.3 million ac (2.5 million ha) of this area is quantified as able to support individual habitat resource needs. The central and northern populations have over 50 percent of the mapped distribution within management/conservation areas, and ecological diversity in the central and northern populations is higher than in the eastern population based on the number of ecoregions within the mapped distribution (Figure 25). Therefore, we assume there are larger areas of intact habitat in the central and northern populations than the eastern population. However, we consider that all populations currently have a high capacity to withstand or recover from stochastic disturbance events due to the large distribution, ecological diversity, and large amount of management/conservation area that limits habitat disturbance and provides more intact ecosystems.

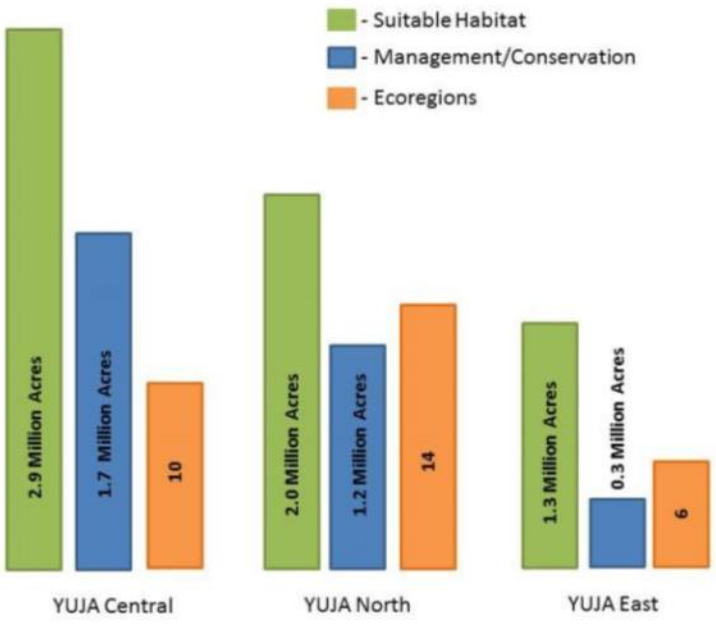


Figure 25: Habitat Elements, *Yucca jaegeriana*

Although we do not have good population estimates, we consider it reasonable to assume redundancy is high within YUJA Central, YUJA North, and YUJA East as these populations are spread across very large, intact habitat areas that support resource needs. There is no evidence to support recent (post-Holocene) population size reductions based on genetic information (Smith *et al*. 2011, p. 10) or to indicate a range contraction over the last 40 years based on distribution mapping (Rowlands 1978, p. 52). Additionally, plants are located primarily on federal lands with less occurrence of anthropogenic development. Adverse impacts to the species are spread across a 6.3 million ac area (2.5 million ha) so it is not likely that catastrophic events, such as wildfire, would lead to the death of every individual in the three regional populations indicating there is a high degree of species redundancy.

Representation, as measured by the ecological diversity of habitats *Yucca jaegeriana* inhabits, is high as the three populations occupy highly diverse areas within the Mojave, Great Basin, and Sonoran Deserts that encompass differences in elevation, soil type, temperature, rainfall, and vegetation communities (i.e., Ecoregions). Also, *Y. jaegeriana* exhibit differences in physical stature and branching arrangement within and across populations. For example, vegetative traits, such as leaf length and height to first branching, vary among individuals and across populations (Godsoe *et al.* 2009, p. 598). This information may suggest a high degree of flexibility for Joshua tree response to environmental conditions, which may provide the species the capacity to withstand extreme environmental events resulting in a high degree of species representation.

Hybrid Zone (Tikaboo Valley)

The two Joshua tree species and their respective pollinators occur in a narrow zone of sympatry located in the Tikaboo Valley in Nevada (Rowlands 1978, p. 179; Starr *et al.* 2012, p. 3), occupying approximately 131,107 acres (53,057 ha), 99.6 percent of which is suitable. Of those suitable acres, 2,551 ac (1,032 ha), or 1.9 percent has management/conservation potential, and four ecoregions are represented

Hybrids are formed as both species of moths visit both species of Joshua trees (Smith *et al.* 2009, p. 5225; Starr *et al.* 2012, p. 9). Pollinator behavior determines the magnitude and direction of gene flow between the two Joshua tree species (Starr *et al.* 2012, p. 9), which is likely driven by the ability of *Tegeticula antithetica*, the primary pollinator of *Yucca jaegeriana*, to successfully pollinate both species (Smith *et al*. 2009, p. 5225; Starr *et al.* 2012, p. 9). Approximately one third of the plants in this population are of hybrid origin (Starr *et al.* 2012; p. 10), and cannot be classified as either *Y. brevifolia* or *Y. jaegeriana*. Almost all the land within the hybrid zone is owned and managed by the BLM.

7.0 FUTURE CONDITION

In this section we describe our analysis of the potential future threats to *Yucca brevifolia* and *Y. jaegeriana* populations and how those potential stressors may influence population resiliency and species redundancy and representation in the future. We begin with a discussion of the potential threats across the landscape that may affect the future condition and develop two possible future scenarios. Next, we assess future population resiliency based on the two scenarios. Lastly, we evaluate the species future condition in terms of its resiliency, redundancy, and representation.

The same uncertainties identified in Section 6.0 above apply to the conclusion we have made based on our future condition assessment.

Future Trend Assessment

Drawing on the information and evaluations in the Current Condition Section above, we consider how the stressors may change over time and how that change may negatively or positively impact the species' habitat and demographic needs in the future based on the relationships depicted in Figure 17. In our discussion of future conditions, we describe two scenarios for those stressors we have considered as drivers for potential changes of the two species' current condition into the future. These are just two of many potential scenarios that may occur in the future for *Yucca brevifolia* and *Y. jaegeriana*.

For a long-lived species such as Joshua tree (~200 years) it is difficult to determine realistic future effects without a large degree of speculation. However, our analysis of the magnitude and likelihood of stressors continuing into the future is based on the best information currently available and our judgement on what those effects mean to the viability of the species into the future. We did not include a future conditions discussion for the stressors we determined were not significant to population or species viability (i.e., herbivory, nitrogen enrichment, and overutilization (see Section 6.0 above).

Future fire effects were assessed using a model of invasive annual grass potential derived for BLM's Mojave Basin and Range Rapid Ecoregional Assessment (REA). REAs examine ecological values, conditions, and trends at an ecoregional scale and are intended to inform landscape-scale direction rather than site-level decision making by the BLM (Comer *et al*. 2013, p. 7). We used the REA's model of invasive annual grass potential to evaluate Joshua tree's future vulnerability to an altered fire regime that results in larger, more frequent fires.

For climate and habitat loss future scenarios, we used the Intergovernmental Panel on Climate Change (IPCC), Special Report on Emission Scenarios (SRES) to evaluate future conditions and created two scenarios, Scenario I and Scenario II, to capture how the potential stressors may react to differences in future levels of greenhouse gas (GHG) emissions. These emission scenarios are not predictions, but two examples from among the many plausible future climate projections (Cayan *et al*. 2008, p. S38) that might affect the distribution of Joshua tree through the end of this century. We used the EPA's Global Change Research Program's Integrated Climate and Land Use Scenarios (ICLUS) to estimate change in future human population densities within the range of Joshua tree through 2095 (EPA 2009, entire). Refer to Appendix B for information on how we used the ICLUS model to identify future urban development. These human population estimates were based on the IPCC SRES, which was developed to provide consistent benchmarks for local and regional land-use change studies as part of the larger international climate change effort (IPCC 2007, entire). Each scenario makes certain assumptions about how human societies develop in terms of demographics and economic development, technological change, energy supply and demand, and land use change. These variables will influence the level of future GHG emissions, which relates to how the climate may change in the future. The probability of either future condition scenario occurring is the same.

Scenario I forecasts a world with a globally coherent approach to sustainable development and more ecologically friendly. It is based on the B family of scenarios that predict GHG emissions will increase until approximately 2050 and then decline. This emission scenario is considered a low emission scenario (Cayan *et al*. 2008, p. S23). Scenario II forecasts a more divided world. It is based on the A Family of scenarios that predict GHG emissions will increase though the 21st century. This emission scenario is considered a medium-high emission scenario (Cayan *et al*. 2008, p. S23)

Potential Stressors and Future Effects on *Yucca brevifolia* Populations.

As stated above, a future stressor analysis is particularly challenging for this species because it has a relatively long life span (~200 years) and long time to sexual maturity (up to 30 years), so a meaningful timeframe that incorporates enough generations to detect potential population and species-level responses to changes in future stressors would be at least 200 years to incorporate three or four generations (a generation time is likely between 50–70 years). Unfortunately, the information on potential future urban growth or climate models becomes more uncertain over such a long time span. As a result, based on the information available on potential future conditions, we selected the timeframe from the present through the end of the 21st century, to evaluate Joshua tree future conditions. Though this time period likely incorporates only one generation of Joshua tree, we evaluated how stressors up to the end of the century may affect vital rates, such as seedling establishment and survival or adult survival, which relate to population stability or growth and thus future resiliency (See Figure 17).

In our future stressor analysis, we included the current stressors of altered fire regimes and invasive plants, the effects of climate change, and habitat loss that have the potential to affect future Joshua tree resilience at the population level. We also considered that these stressors may act synergistically to create an effect greater than the sum of their separate effects (Table 10).

Altered Fire Regimes and Invasive Annual Grasses

The above current condition assessment concluded that fire regimes across the range of *Yucca brevifolia* have likely increased in frequency over recent decades in certain parts of the range, and that this broader altered fire regime has been largely driven by the proliferation of invasive annual grasses which act as fine fuels and connect vegetation previously less connected. Recent fires have predominantly occurred within mid-elevation areas, where a large proportion of the *Y. brevifolia* range occurs. *Yucca brevifolia* may be vulnerable to fire because evolution and adaptation by native Mojave Desert plant species in general have not been largely influenced by fire. We anticipate that fires with increasing intensity (i.e., increasing energy output) due to invasive grass proliferation would result in increased fire severity, with potential broader scale ecosystem effects such as loss of above- and below-ground soil organic matter, increased soil erosion, and longer recovery times for burned areas (Keeley 2009, p. 118).

Direct effects to *Yucca brevifolia* from fire include immediate individual mortality, particularly to smaller stature plants less than 1 m (3.3 ft) in height, and potentially an increase in the mortality rate and reduced survivorship within populations over time. Young plants are most vulnerable to fire because they have their active meristems close to the ground. Increased fire frequency and burn severity could drive *Y. brevifolia* population structure toward older and larger size classes in burned areas, because smaller plants are more susceptible to fire and because germination and recruitment of new plants relies on avoidance of fire. Indirect effects to *Y. brevifolia* from fire include degraded seed bank, loss of aboveground vegetation that could serve as nurse plants to seedlings, and alteration in seed-caching rodent dynamics within *Y. brevifolia* stands. Burned areas are also more likely to be re-colonized by invasive annual grasses, creating a feedback loop for future fire dynamics. In general, altered fire regimes could degrade these habitat resource needs within the current distribution of *Y. brevifolia* in the future.

Due to the limited information available on population distribution patterns and abundance in each population, estimating the potential future impacts of altered fire regimes on population resiliency is difficult. What we can more reliably predict is how particular resource needs are related to future effects from fire and which demographic needs could be influenced (Figure 26).

As earlier illustrated in Figure 18, current fire return intervals across *Yucca brevifolia* populations are generally greater than 300 and 500 years. Because of the close coupling of invasive grasses acting as fine fuels resulting in larger and more frequent fires within the Mojave Desert, we used data from the BLM's Mojave Basin and Range Rapid Ecoregional Assessment (Comer *et al*. 2013, p. 79) that models the potential abundance of invasive grass within *Y. brevifolia* populations to assist in projecting future habitat conditions for *Y. brevifolia* (Table 8). The model was derived from invasive grass field data and the following landscape variables: elevation, aspect, distance to recent large fire, geology, distance to hydric soils, distance to intermittent streams, landform, ombrotype [a measure of ombroclimatic (moisture) gradients], soil pH, density of primary roads, density of secondary/local roads, percent sandy soil, slope, and thermotype (a measure of thermoclimatic [temperature] gradients).

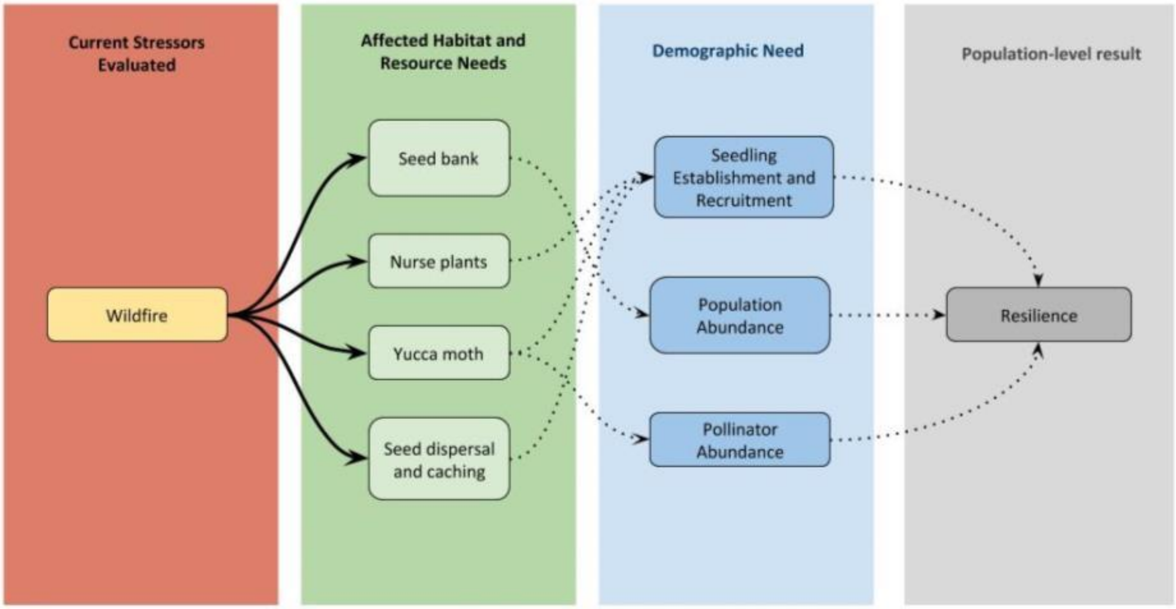


Figure 26: Possible relationships among wildfire, habitat resource needs, and demographic needs, which could ultimately have an adverse effect on population resilience

Table 8: Invasive Grass Potential for *Yucca brevifolia* populations

Y. brevifolia South	
25% - 45% Cover	1.0 percent
15% - 25% Cover	0.4 percent
5% - 15% Cover	0.6 percent
<5% Cover	35.4 percent
No/Low Cover	56.7 percent
No Data	2.3 percent
Y. brevifolia North	
25% - 45% Cover	3.9 percent
15% - 25% Cover	4.9 percent
5% - 15% Cover	4.5 percent
<5% Cover	23.0 percent
No/Low Cover	54.6 percent
No Data	0.9 percent

Scenario I – All Populations

Under Scenario I, we considered areas within the mapped distribution that are classified to have a 25–45 percent invasive grass cover are more vulnerable to an altered fire regime consisting of larger, more frequent fires with higher burn severity. This cover category includes approximately 1 percent of the YUBR South and 3.9 percent of the YUBR North current mapped distribution.

Under this scenario we anticipate a longer-term impact to the YUBR North population as fire frequency increases and results in diminished recruitment and reduction in population abundance but we lack information to provide a reasonable prediction on the timing of this potential longer-term effect. Finally, we anticipate that fires could lead to the loss of moths (*Tegeticula synthetica*) that pollinate *Yucca brevifolia* through direct mortality.

Scenario II – All Populations

Under Scenario II, we considered that habitat areas that are classified to have a 15–45 percent invasive grass cover will experience an altered fire regime consisting of larger, more frequent fires with higher burn severity. This cover category includes approximately 1.4 percent of the YUBR South and 8.8 percent of the YUBR North current mapped distribution. Under this scenario we anticipate a longer-term impact to both YUBR South and YUBR North populations as fire frequency increases and results in diminished recruitment and reduction in population abundance but we lack information to provide a reasonable prediction on the timing of this potential longer-term effect. Finally, we anticipate that fires could lead to the loss of moths (*Tegeticula synthetica*) that pollinate *Yucca brevifolia* through direct mortality.

Climate Trends

The current condition assessment concluded that specific climate-related stressors could be currently affecting *Yucca brevifolia* populations and the species distribution across the range may be generally constrained by temperature (summer maximum and winter minimum) and precipitation (both summer and cool season). Below, we discuss potential future climate conditions and how those may influence population resiliency. To address uncertainties associated with future conditions and viability, we considered the most important climate change stressors and their likely impacts on resiliency of each population. First, we identified metrics of climate change thought to be most influential (e.g., temperature or precipitation thresholds) based upon biological considerations (Figure 27) and availability of information from climate models such as the National Center for Atmospheric Research (NCAR) GIS program. Next, we examined models projecting future temperature and precipitation under two different climate scenarios (Scenario I and II) to determine how these metrics may change in the future. Our scenarios describe two possible climate futures through the end of the 21st century, based upon how much greenhouse gases are emitted in the years to come. Scenario I (B1) represents a future where global emission rates will level off mid-21st century, while Scenario II (A2) represents a future where emission rates will continue to increase throughout the 21st century.

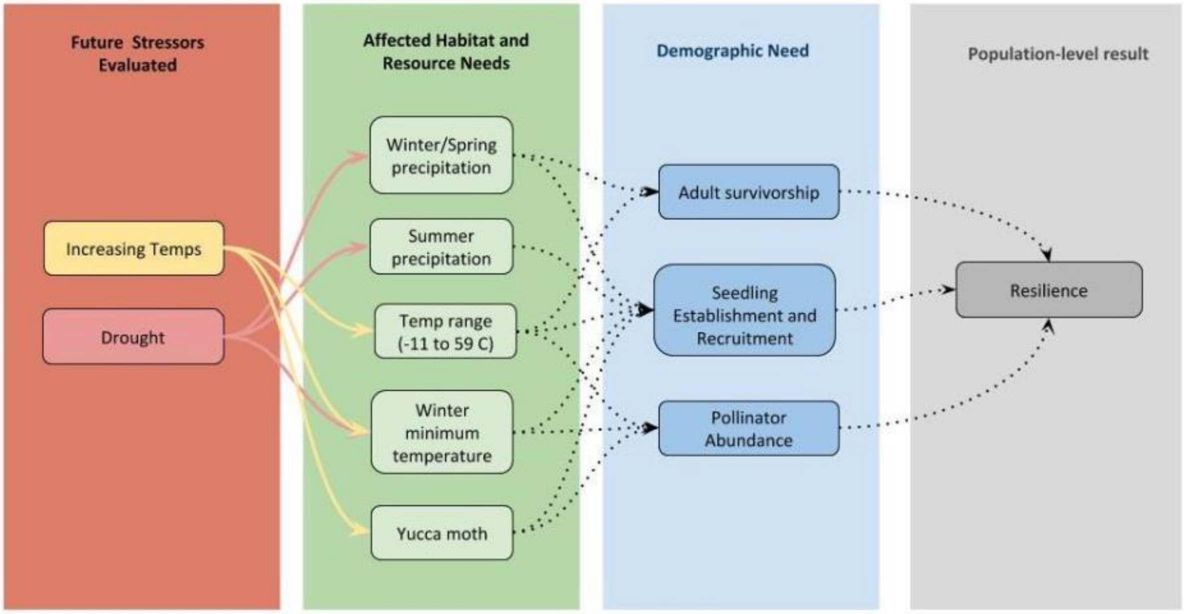


Figure 27: Possible relationships among potential future climate change stressors, habitat resource needs, and demographic needs, which could ultimately have an adverse effect on population resilience

The most recent IPCC Assessment Report in 2014 adopted four greenhouse gas concentration trajectories, or Representative Concentration Pathways (RCPs), to model future climates. These RCPs describe four plausible future climates, based on future amounts of greenhouse gas emissions. RCP 2.6 is similar to the B1 scenario, where global emissions peak between the years 2010-2020, and decline considerably thereafter. RCP 8.5 is similar to the A2 scenario, where emissions continue to rise throughout the 21st century. To use the best available climate science, we also examined models projecting future temperature and precipitation under RCP 2.6 and RCP 8.5. However, we found no major differences in predictions between models incorporating the B1 scenario and RCP 2.6, nor among models incorporating the A2 scenario and RCP 8.5 (see Appendix C). Therefore, we retained climate models based upon Scenario I (B1) and Scenario II (A2), to maintain consistency with modeled land use changes in the EPA ICLUS model.

We did not model future distribution based on predicted climate change scenarios. Instead, we used future scenarios to perform a qualitative evaluation of the impact of climate change on the current distribution. Similar to the approach used to assess other future conditions, we used a scenario planning framework to examine future climate conditions. Scenario planning is being increasingly employed to evaluate impacts of potential climate change, and can inform decision making under high uncertainty. Rather than focusing only on the most likely predictions, scenario planning identifies a range of possible future states. Scenarios are not predictions, and probabilities are not assigned to specific outcomes. By recognizing the limits of projections and acknowledging deep uncertainty, decision makers are not restricted to preparing for only one outcome, and can still act in the face of climate change while retaining flexibility (Star *et al.* 2016, p. 89). Our goal was to present information related to future climate outcomes, not to evaluate quantitative assessments of climate change on future Joshua tree distribution, therefore we did not construct ecological niche models (e. g., species distribution models). Furthermore, ecological niche models are often criticized for inaccurate projections of future occurrence (Fitzpatrick and Hargrove 2009, p. 2256). This is especially true for species where current distribution data are not extensive across the species range or information about physiological thresholds is lacking, such as Joshua tree (Pearson and Dawson 2003, p. 362). Given the absence of information about the adaptive capacity of Joshua tree, in combination with gaps in the occurrence data across the species' range, the probability of spurious conclusions seemed high. Although a rangewide ecological niche model was not likely to be informative at this time, such an approach could be recommended for future efforts, when a more comprehensive Joshua tree occurrence data set is acquired.

Future climate projections were obtained from coarse climate data (e.g., Global Circulation Models or GCMs) downscaled to create a finer spatial resolution data set. There are a variety of GCMs to choose from and the direction and extent of projected climate change impacts varies considerably among different models (Gonzalez 2017, p. 103). This is particularly true for predicted changes in precipitation, as this environmental characteristic varies widely across a landscape and climate modeling efforts may be constrained by a lack of spatial uniformity (Gonzalez 2017, p. 117). We used the Community Climate System Model (CCSM) developed by the NCAR, because this model incorporates fine scale resolution data across the entire U.S. and uses an ensemble average of various IPCC climate outputs to minimize spurious effects of high variability (Hoar and Nychka 2008, p. 2). However, we recognize the NCAR CCSM model has been shown to have a propensity for over predicting wetter conditions, when compared to other models at larger geographic scales such as across the entire southwestern region of the U.S. (Seager *et al*. 2007, p. 1181). Given the high degree of spatial heterogeneity across the Joshua tree range we evaluated how each population may be impacted by projected changes in climate based on the NCAR model.

Climate Metrics

Increasing maximum summer temperature

Summer is the season when ambient temperatures reach their maximum and increasing maximum summer temperatures may primarily alter adult survivorship. As stated previously, laboratory studies identified an upper temperature threshold of 59°C (138°F) for *Yucca brevifolia* (Smith *et al*. 1983, p. 16), but we lack information to determine what the maximum temperature threshold might be in an environmental setting. *Y. brevifolia* populations in a natural setting do not appear to have experienced mean maximum summer temperatures above 44°C (111°F) in the recent past (Figure 28). Higher temperatures are predicted for the future and adult individuals may suffer from physiological heat stress if temperatures go above 59°C (138°F), which may result in individual mortality.

Climate modeling efforts for Joshua Tree National Park indicated a 3°C increase in average July temperature by the end of the century that may lead to reduced distribution, perhaps via reduced adult survivorship and/or reduced recruitment (Barrows and Murphy-Mariscal 2012, p. 35). Under both climate scenarios I and II, average summer temperature increases ≥ 3°C are projected for some regions where *Y. brevifolia* populations occur (Figure 29).

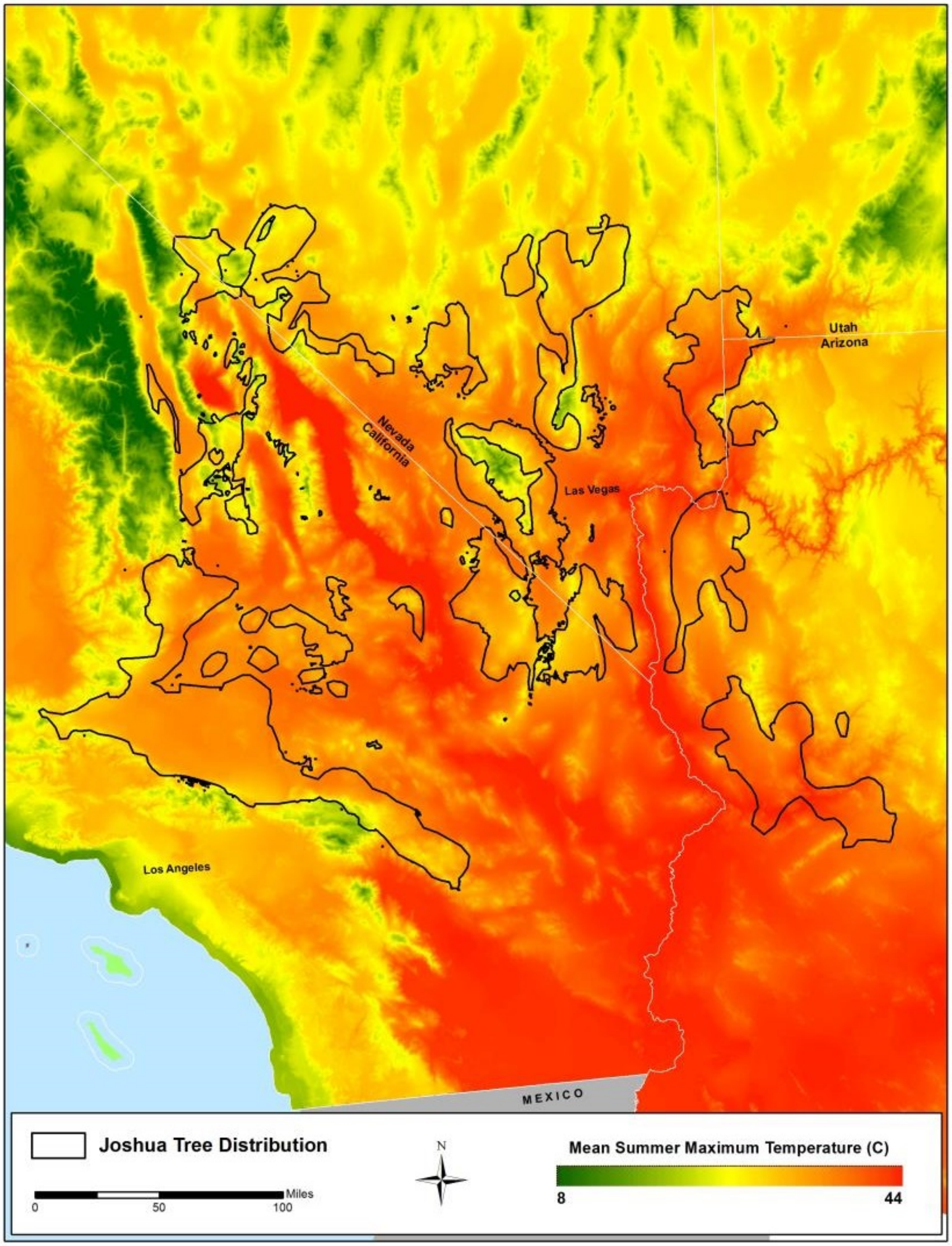


Figure 28: Mean Summer Maximum Temperature

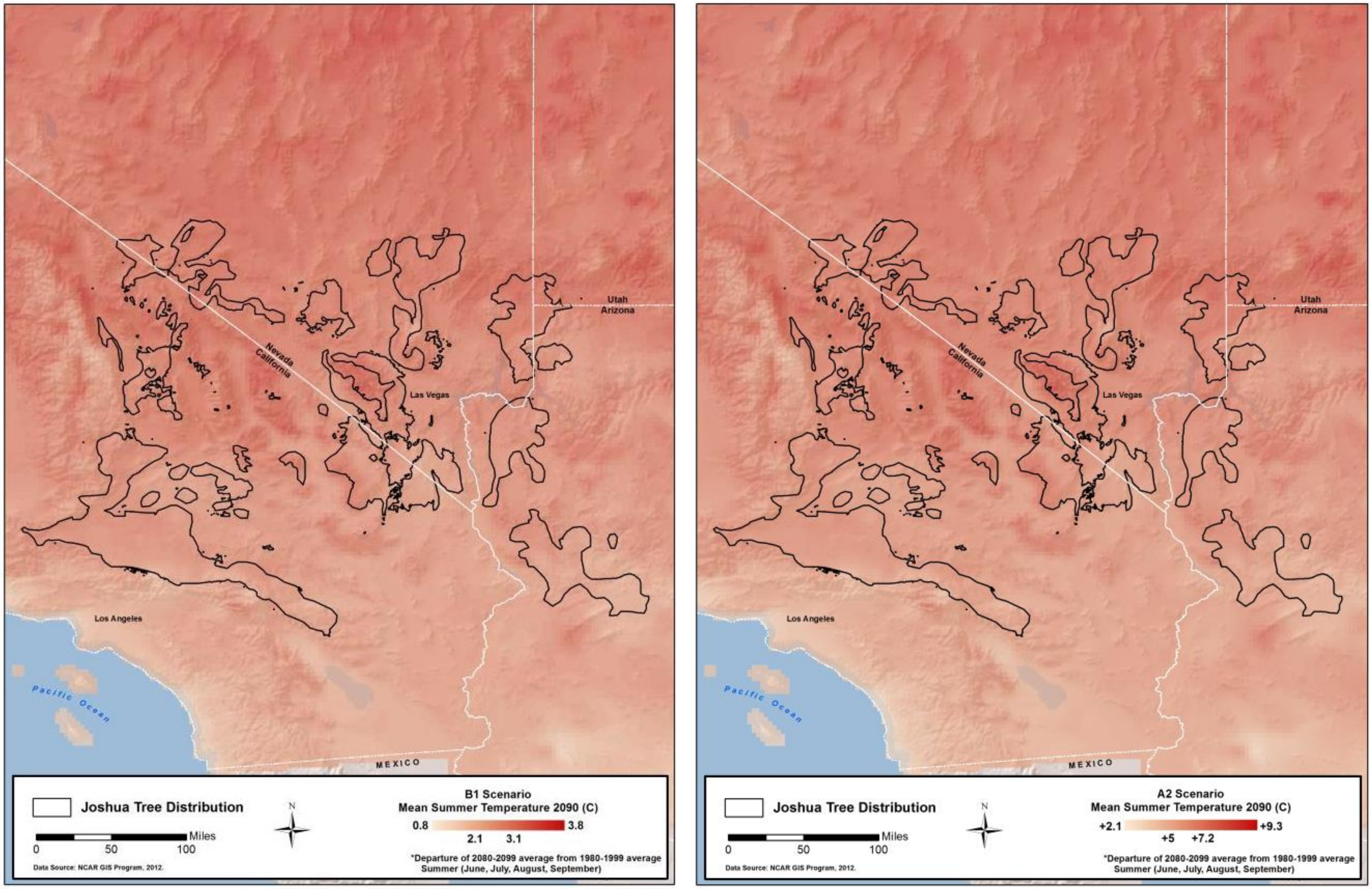


Figure 29: Projected Departure of Average Summer Temperature in 2090, B1 (Left) and A2 (Right) Emission Scenarios

Increasing minimum winter temperature

Winter is the season when ambient temperatures reach their minimum and extremely cold temperatures may primarily alter adult survivorship and pollinator abundance. As stated previously, laboratory studies identified a lower temperature threshold of -11°C (12°F) for *Yucca brevifolia* species (Smith *et al*. 1983, p. 16), and we lack information to determine what the minimum temperature threshold might be in an environmental setting. *Y. brevifolia* populations in a natural setting do not appear to have routinely experienced minimum winter temperatures below -11°C (12°F) in the recent past (Figure 20). Climate change projections for some desert regions include colder winter temperatures as a result of shifts in the timing or reductions in the amount of winter precipitation (Kimball *et al*. 2010, p. 1561; Abatzoglou and Kolden 2011, p. 475) and a similar pattern could occur in the Mojave, which might lead to increased mortality of individual plants and/or pollinators. Alternatively, elevated CO_2 levels are predicted to increase the freezing tolerance of *Y. brevifolia* (Loik *et al.* 2000, p. 53) which could result in a large range expansion to higher elevations or further north if significant amounts of new habitat become climatically suitable (Dole *et al*. 2003, p. 142).

Climate models also indicate overall increases in average minimum winter temperature which could both positively and negatively alter adult survivorship, seedling establishment and recruitment, and pollinator abundance. If all three demographic needs are limited by extremely cold temperatures, then an increase in average minimum winter temperature could actually lead to population expansion into areas that were previously unsuitable climatically. However, there is evidence to suggest that exposure to temperatures below 4°C is necessary for optimal growth, reproduction, and recruitment for *Y. brevifolia* (Went 1957, p. 173). Additionally, some yucca moth species will not exit diapause until a minimum temperature threshold is reached (Powell 2001, p. 679) and it is unknown if this is also true for pollinating moths described here. Thus, higher overall temperatures in the winter could lead to reduced growth, recruitment, and reproduction, and pollinator abundance. Under climate Scenario II, average winter temperature increases ≥ 5°C are projected for some regions where *Y. brevifolia* populations occur (Figure 30), which could potentially negatively influence populations, since exposure to short periods of cold temperatures (below approximately 4°C) might be necessary for optimal growth, reproduction, and recruitment.

Reduced summer and cool season precipitation

Although minimum and maximum precipitation thresholds are unknown, *Y. brevifolia* populations rely on some amount of summer and winter precipitation. Precipitation is projected to decrease overall in the southwest in the future but less is certain regarding the timing and extent of shifts in precipitation patterns. Larger germination events and greater seedling emergence have been correlated with higher summer precipitation (Reynolds *et al*. 2012, p. 1652; Esque *et al*. 2015, p. 87), indicating that seedling establishment and recruitment could primarily be altered by reduced summer precipitation. Additionally, seedling establishment and recruitment could be altered by reduced winter precipitation, as plants appear to rely on cool season (winter plus fall and spring) precipitation for survival (Reynolds *et al*. 2012, p. 1653). Drought frequency, duration, and intensity are also predicted to increase in the future throughout the range of *Y. brevifolia* populations. Impacts associated with drought remain difficult to model and spatial information identifying location and magnitude of future drought impacts is largely nonexistent. Since drought is difficult to quantify, we used climate metrics related to changes in temperature and precipitation as proxies to examine potential future impacts resulting from drought. Under both climate scenarios I and II, summer precipitation change varies greatly across the range of *Y. brevifolia* populations, with some areas projected to receive up to an 8 mm (0.31 in) reduction in precipitation while others may receive up to a 7 mm (0.28 in) increase in precipitation (Figure 31). Cool season precipitation (fall, winter, spring) is projected to stay the same or slightly increase for most areas under both climate scenarios I and II (Figure 32).

A discussion of how climate change may affect the future condition of each population is presented here. Climate metrics pertinent to each population are provided and information is summarized according to geographic location.

Future Scenarios – Climate Change

YUBR South

Under Scenario I, mean summer temperatures are projected to increase by 1–2°C in most areas, and mean winter temperatures are predicted to increase 1–1.5°C. Summer precipitation is projected to roughly stay the same for most areas, with a 1.1 mm reduction forecast for a very small area. Winter precipitation is projected to increase slightly (up to 10 mm) in most areas and stay the same in a very small area.

Under Scenario II, mean summer temperatures are projected to increase by 3°C in most areas, with a 2°C increase predicted for a much smaller area and mean winter temperatures are predicted to increase by 3–5°C. Summer precipitation is projected to roughly stay the same in a large portion of the area while a 5–10 mm increase is predicted for a small area. Cool season precipitation is projected to increase 10–20 mm for approximately two-thirds of the area and stay the same for the remaining one-third of the area.

YUBR North

Under scenario I, both mean summer temperatures and mean winter temperatures are projected to increase 1–2°C throughout areas within the current mapped distribution. Summer precipitation is projected to roughly stay the same for about half of the area, with a decrease in precipitation up to 5 mm predicted for the northern areas and a slight increase (5–10 mm) predicted for a very small portion of the area. Cool season precipitation is projected to increase from 5–20 mm throughout the area.

Under Scenario II, mean summer temperatures are projected to increase by 3°C in most areas, with a 4°C increase predicted for a smaller area for this population and mean winter temperatures are predicted to increase by 2.5–5.5°C. Summer precipitation is predicted to stay the same in approximately half of the area with a decrease in precipitation up to 7.5 mm predicted for the northern areas and a slight increase (up to 5 mm) projected for a very small portion of the area. Cool season precipitation is projected to increase in all areas up to 20 mm.

Habitat Loss

The above current condition assessment concluded that across the range, habitat loss may include urban expansion and development, military installation expansion and training activities, renewable energy development, grazing, and OHV activity. Future habitat loss due to urban expansion and development, military installation expansion and training activities, and

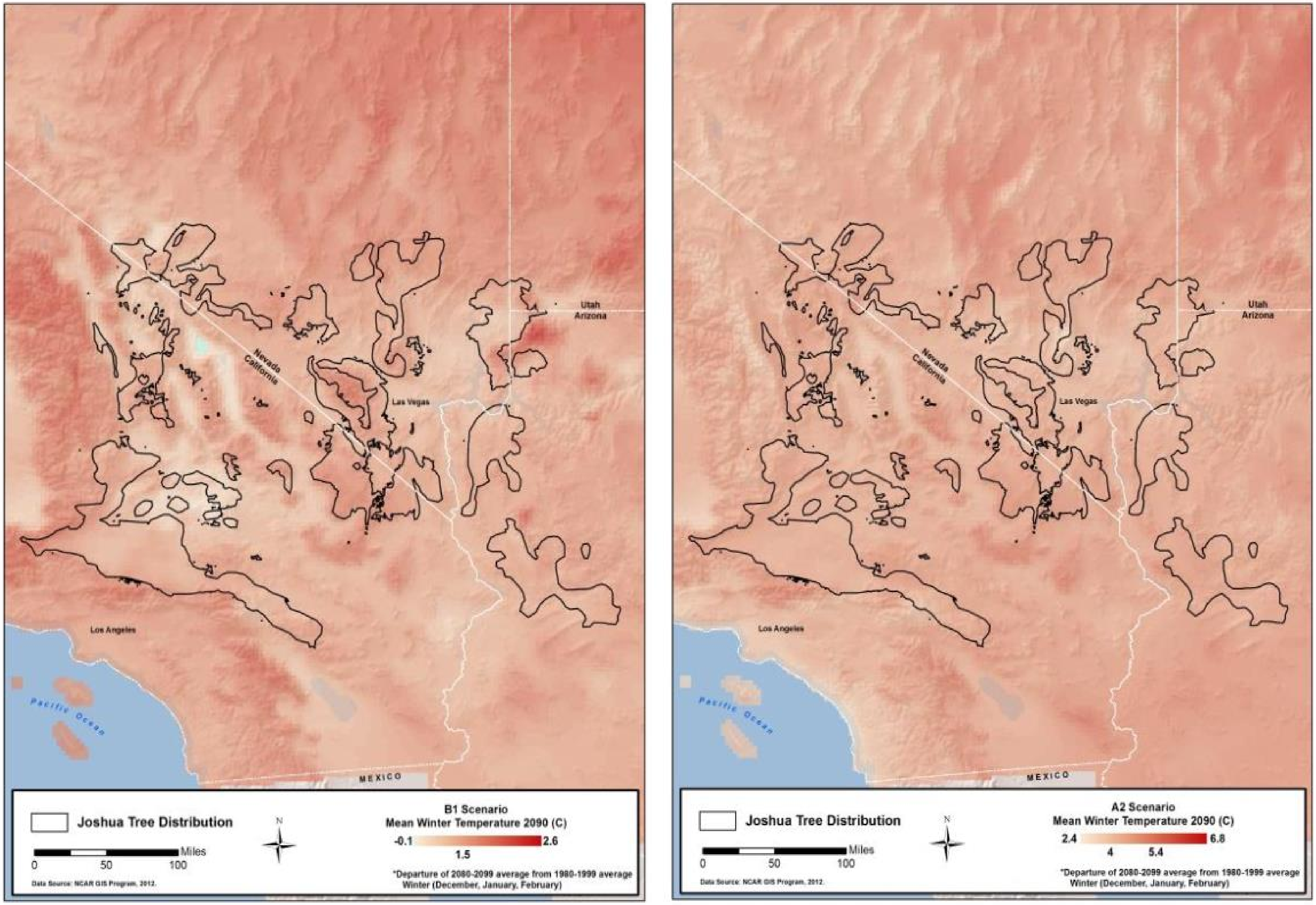


Figure 30: Projected Departure of Average Winter Temperature in 2090. B1 Emission Scenario I (Left) and A2 Scenario II (right)

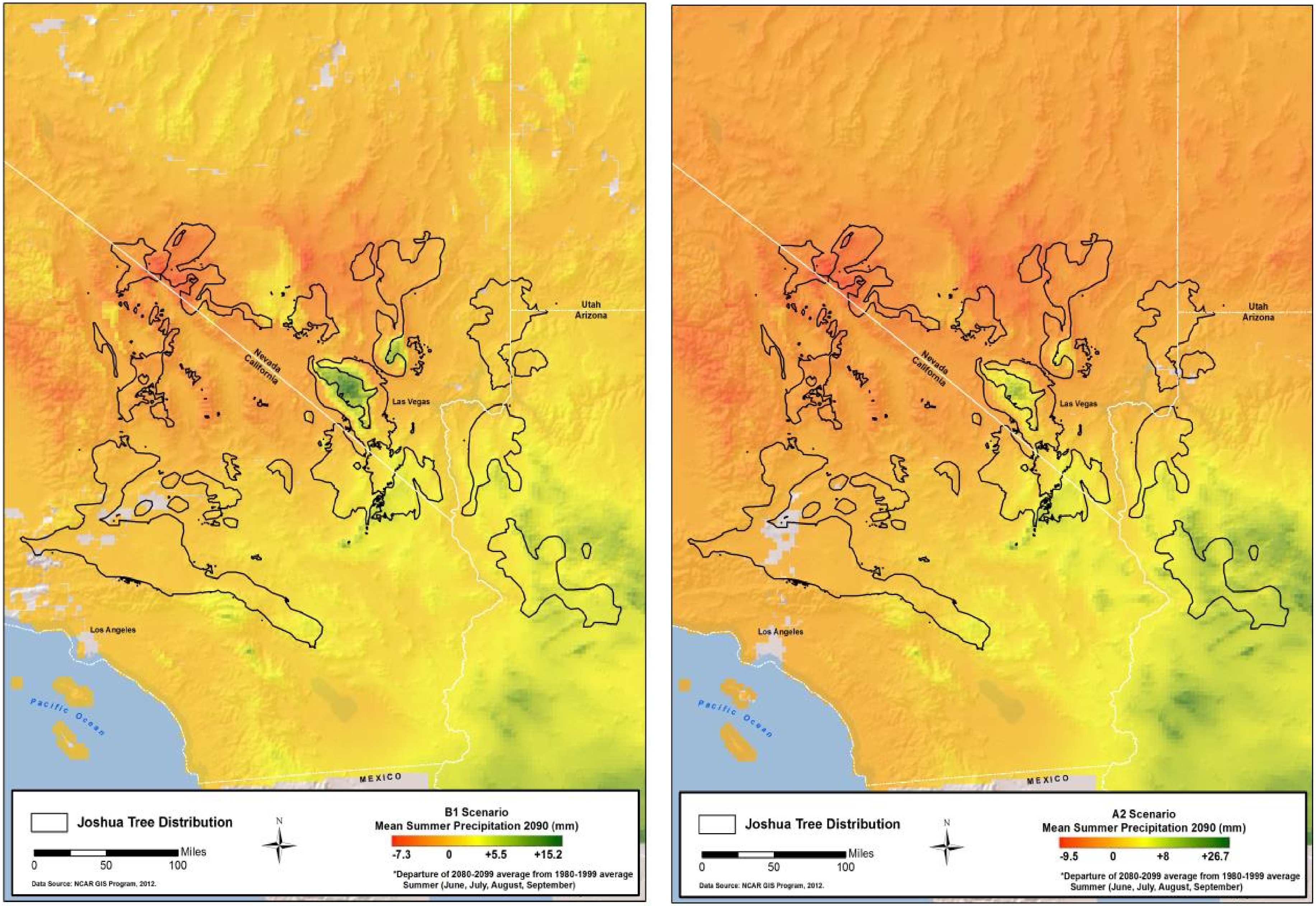


Figure 31: Projected Departure of Average Summer Precipitation. B1 Emission Scenario (Left), and A2 Scenario II (Right)

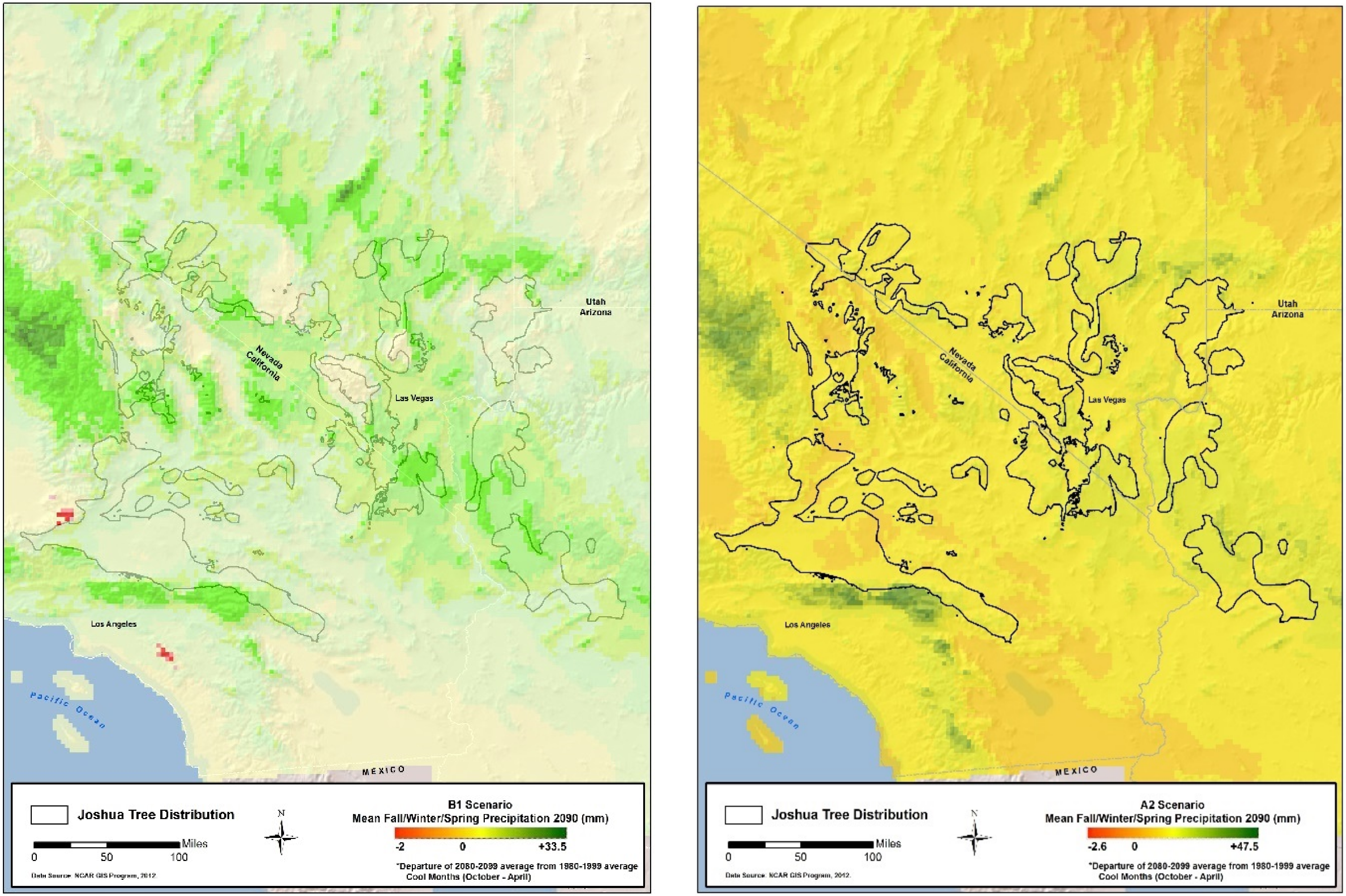


Figure 32: Projected Departure of Average Cool Season Precipitation. B1 Emission Scenario I (Left), and A2 Scenario II (Right)

renewable energy development could degrade future habitat resource needs within the current distribution of Joshua tree (Figure 33) and result in a decline in distribution on lands without management/conservation potential. Below we discuss the potential future habitat loss that may occur for *Yucca brevifolia* and measures currently in place that may limit such loss. We assume that future grazing and OHV activity will not influence population resiliency based on available information.

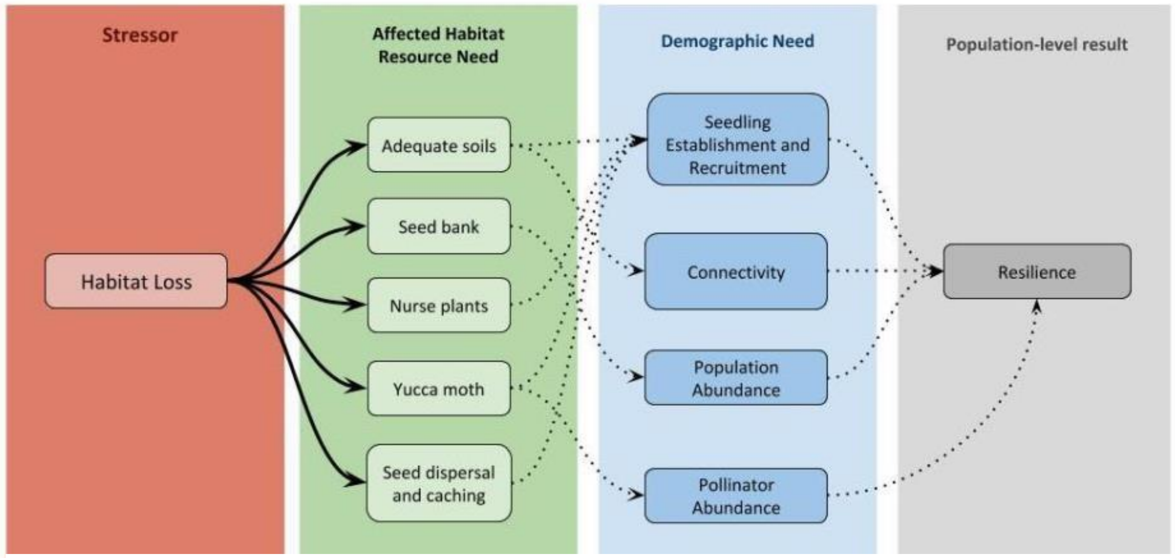


Figure 33: Possible relationships among habitat loss, habitat resource needs, and demographic needs, which could ultimately have an adverse effect on population resilience

Urban Expansion and Development

We used the ICLUS modelling tool to forecast housing density growth to the year 2095 within the current mapped distribution for *Yucca brevifolia* based on two different emission scenarios (EPA 2009, entire). Future urban expansion patterns will likely reflect current trends with concentrated growth across expanding around existing urban areas in the western Mojave Desert (Comer *et al*. 2013, p. 116) such as surrounding the cities of Victorville, Lancaster, and Palmdale. Some areas within the current mapped distribution could be more affected by habitat loss than others. For example, 51 percent of the mapped distribution in the YUBR South population falls within private lands versus 2.4 percent in the YUBR North population. This loss of habitat could affect resource needs, reduce the distribution, and lead to a reduction in population resiliency. Additionally, urban expansion could result in a more fragmented regional population, which could reduce future genetic exchange and connectivity. We anticipate that the large proportion of lands under federal management and the existing state and city ordinances (Table 3) that are in place to protect *Yucca brevifolia* from harvesting will continue, which may help to lessen the effects of habitat loss due to urban expansion and development.

Military Activities

Edwards Air Force Base, Fort Irwin National Training Center, China Lake Naval Weapons Station, Nellis Air Force Base, and Twentynine Palms Marine Corps Air Ground Combat Center are military installations either entirely within or partially within the current mapped distribution for *Yucca brevifolia*. Currently, 12 percent of the mapped distribution in the YUBR South population falls within military installations and 12.5 percent of the YUBR North population falls within military installations. We anticipate loss of suitable habitat and individual plant mortality could occur in recent expansion areas. However, these installations have developed Integrated Natural Resource Management Plans (INRMPs) that incorporate avoidance and minimization measures that could reduce individual fatalities of *Yucca brevifolia* and disturbance of their habitat (see Current Condition above). These plans also have the potential to implement monitoring activities to improve our understanding of future *Y. brevifolia* demographic trends and population resiliency.

Renewable Energy Development

Renewable energy development can degrade and potentially remove individual plants and *Yucca brevifolia* habitat. In California, the Desert Renewable Energy Conservation Plan (DRECP) designates approximately 388,000 acres of development focus areas where it would apply a streamlined review process to applications for projects that generate renewable energy on BLM lands (Service 2016, p. 18). Of those acres, approximately 49,755 ac (20,135 ha) fall within the mapped distribution for *Y. brevifolia*. However, the DRECP contains measures to avoid removing individual plants by avoiding areas classified as Joshua Tree Woodland (DRECP Volume II, p. II.3-55). This would reduce the number of individual trees and habitat potentially lost to renewable energy development under the DRECP. Within the current mapped distribution for *Y. brevifolia* there are no areas designated under BLM’s Programmatic Environmental Impact Statement for Solar Energy Development in Six Southwestern States (Solar PEIS) that overlap. There are also no areas of the current mapped distribution that overlap with BLM’s current pending lease areas. Information on acreage projections for future development of renewable energy projects on non-federal lands is unavailable but we assume any future loss to Joshua tree individuals and habitat associated with renewable energy development on private lands will be reflected in the ICLUS projections for future urban development.

Land Management and Conservation

Areas within the current mapped distribution for *Yucca brevifolia* that are located within NPS units, BLM ACEC’s and NLCS lands, and other state lands (State Parks and Ecological Reserves) have management/conservation potential not afforded areas outside of these designations. These areas limit habitat disturbance and provide more intact ecosystems and may provide areas that support more resilient local populations. We anticipate that in the future, these areas will continue to have protections and be managed to limit disturbance. Within the populations for *Y. brevifolia*, YUBR South includes 32.7 percent of the mapped distribution in these areas and YUBR North has 37.3 percent, for a total of 1,916,486 ac (775,574 ha) that provide more intact ecosystems. Synergistic effects from other stressors could confound protections afforded plants in these areas if increasing temperatures and longer droughts or more frequent and intense wildfires result in negative population growth in these managed and/or conserved areas.

Future Scenarios – Habitat Loss

Under Scenario I, 667,693 ac (270,206 ha) of the current mapped distribution may be lost to urban development and expansion based on projections in the ICLUS model using scenario B1. All calculated increases in residential housing density were considered no longer suitable to support resource needs regardless of density category (see Appendix B for more information). Renewable energy development continues and projects are built-out according to acreages described under the DRECP, Solar PEIS, and BLM pending land leases. This scenario results in an overall loss of 717,448 ac (290,341 ha) of mapped distribution of *Yucca brevifolia* by 2095, with most loss occurring in the YUBR South population (Table 9, Figure 34). This represents a 14 percent reduction in *Yucca brevifolia* mapped suitable habitat supporting adequate soils, seed bank, nurse plants, yucca moths, and seed dispersal and caching.

Under Scenario II, 1,318,933 ac (533,753 ha) of the current mapped distribution may be lost to urban development and expansion based on projections in the ICLUS report using scenario A2. Renewable energy development continues and projects are built-out according to acreages described under the DRECP, Solar PEIS, and BLM pending land leases. This scenario results in an overall loss of 1,368,688 ac (553,889 ha) of *Yucca brevifolia* mapped suitable habitat by 2095, with most loss occurring in the YUBR South population (Table 9, Figure 34). This represents a 26.3 percent reduction in *Y. brevifolia* distribution supporting adequate soils, seed bank, nurse plants, yucca moths, and seed dispersal and caching.

Table 9: *Yucca brevifolia* Future Habitat Loss by Scenario

Scenario I					
	Mapped Suitable Habitat (ac)	**Mapped Suitable Habitat (ha)**	**Potential Habitat loss (ac)**	**Potential Habitat loss (ha)**	**Potential Percent Loss**
YUBR South	3,255,088	1,268,622	705,356	285,448	21.7%
YUBR North	1,941,701	785,779	12,092	4,893	0.6%
Species Total	5,196,788	2,054,401	717,448	290,341	13.8%
Scenario II					
YUBR South	3,255,088	1,268,622	1,354,815	548,275	41.6%
YUBR North	1,941,701	785,779	13,873	5,614	0.7%
Species Total	5,196,788	2,054,401	1,368,688	553,889	26.3%

Possible Synergistic Effects

The threats discussed above have the potential to operate synergistically, possibly magnifying their individual effects. Table 10 provides examples of these potential synergistic effects.

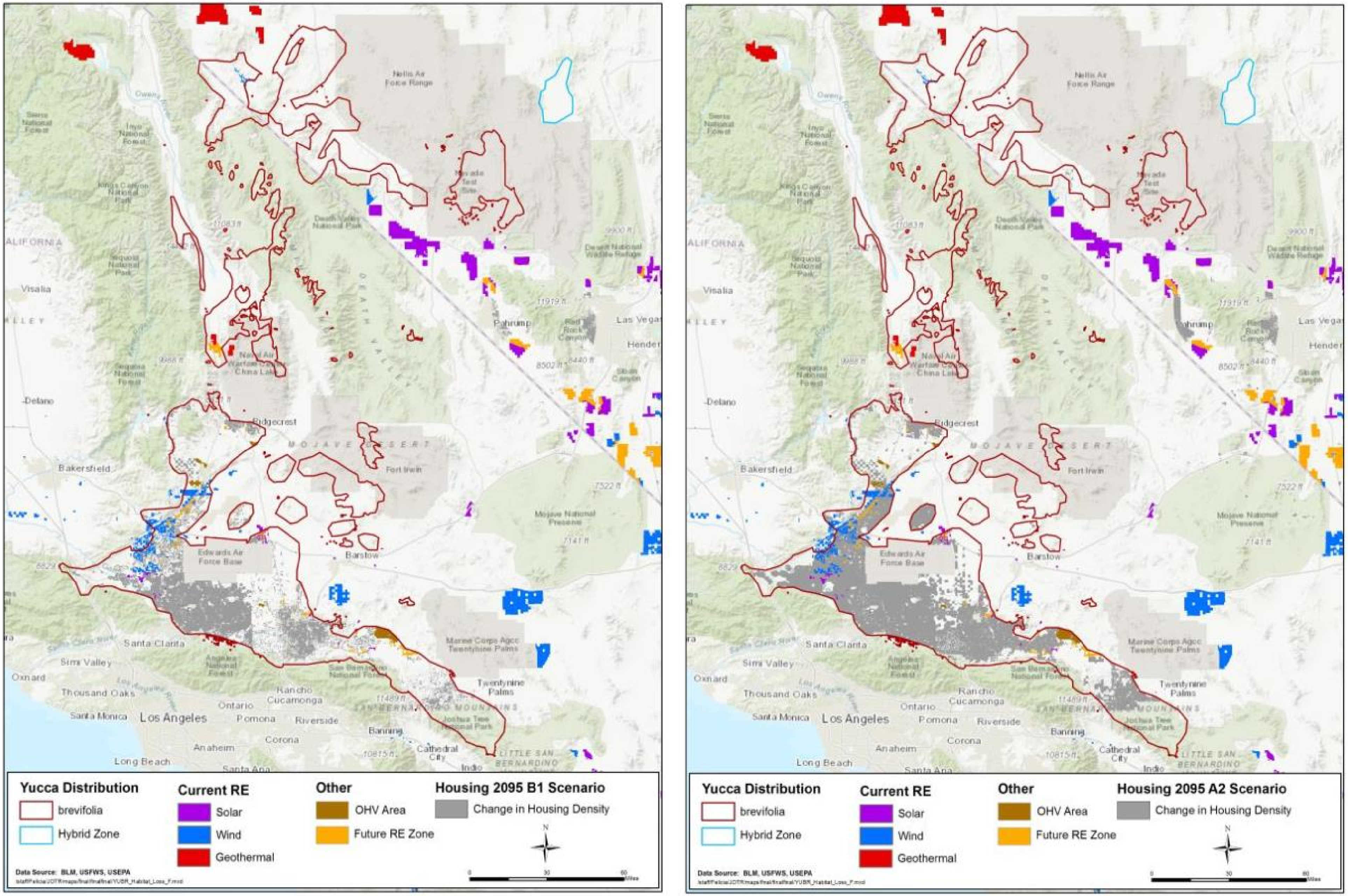


Figure 34: *Yucca brevifolia* Habitat Loss. Scenario I (left) and Scenario II (Right)

Table 10: Synergistic effects of other stressors on the future condition of *Yucca brevifolia* and *Yucca jaegeriana* populations

Stressor	**Potential Synergistic Effects with Invasive Grass Cover and Altered Fire Return Interval**
Increasing winter minimum temperature	Range-wide warming temperatures during winter may diminish the optimal growth conditions that *Yucca brevifolia* and *Y. jaegeriana* plants experience during periods when temperatures drop below 4°C. This in turn prolongs the duration that plants spend at smaller size-classes, when they are most vulnerable to fire.
Habitat disturbance and loss	Invasive annual grass species more readily re-colonize disturbed habitat than do native grass species. This proliferation of flammable fuels may lead to further reductions in mean fire return intervals, as well as larger fires occurring in areas across the range of *Yucca brevifolia* and *Y. jaegeriana* that are being increasingly disturbed (i.e., more frequent and larger fires).
Persistent drought	Trends toward increasingly warmer temperatures and longer periods of dryer conditions (i.e., persistent drought) are believed to be occurring within the range of *Yucca brevifolia* and *Y. jaegeriana*. These conditions deteriorate fire conditions, especially in areas with an abundance of invasive annual grass species that serve as fuel loads. These conditions are likely to further exacerbate the condition of more frequent and larger fires within the range of *Y. brevifolia* and *Y. jaegeriana*.
Synergistic Stressor	**Potential Synergistic Effects with Climate Change**
Invasive grasses and reduced fire intervals	Elevated CO_2 increased above-ground production and seed rain of an invasive grass more than observed in native annuals (Smith *et al*. 2000, p. 81). This may increase the prevalence of invasive annual grasses, with resulting effects of accelerated fire cycles, reduced biodiversity, and altered ecosystem function in SW deserts. This proliferation of flammable fuels may further exacerbate the current condition of more frequent and larger fires across the range of *Yucca brevifolia* and *Y. jaegeriana*.
Synergistic Stressor	**Potential Synergistic Effects with Habitat Loss**
Invasive grasses and reduced fire intervals	Invasive grass species more readily re-colonize disturbed habitat than do native grass species. This proliferation of flammable fuels may further exacerbate the current condition of more frequent and larger fires across the range of *Yucca brevifolia* and *Y. jaegeriana*.
Persistent drought	Trends toward increasingly warmer temperatures and longer periods of dryer conditions (i.e., persistent drought) are believed to be occurring within the range of *Yucca brevifolia* and *Y. jaegeriana*. These conditions slow or prevent the re-colonization of native plant species following loss due to disturbance, instead favoring the establishment of invasive annual grass species. These serve as fuel loads and are likely to further exacerbate the current condition of more frequent and larger fires across the range of *Y. brevifolia* and *Y. jaegeriana*.

Summary of Potential Future Conditions on *Yucca brevifolia* Population Resiliency

YUBR South

In general, under Scenario I, 1.0 percent of the current mapped distribution in this population may experience larger, more frequent fires; an increase in mean winter and summer temperatures; no change in summer precipitation; a slight increase in cool season precipitation; and a 21.7 percent loss of habitat by the end of the century. The amount of management/conservation potential and the number of ecoregions represented does not change (Table 11).

Table 11: *Yucca brevifolia* Future Scenario Summary

Scenario I							
Population	**Percent Future Altered Fire Regime**	**Current Mean Low Temp Range (C)**	**Future Mean Low Temp Range (C)**	**Current Mean High Temp Range (C)**	**Future Mean High Temp Increase (C)**	**Current Percent Suitable Habitat**	**Future Percent Suitable Habitat**
YUBR South	1.0	-5.7 to 4.8	1 to 1.5	23 to 37	1 to 2	87.4	65.7
YUBR North	3.9	-8.1 to 3.6	1 to 2	20 to 36	1 to 2	98.2	97.6
Scenario II							
YUBR South	1.4	-5.7 to 4.8	3 to 5	23 to 37	3	87.4	45.8
YUBR North	8.7	-8.1 to 3.6	2.5 to 5.5	20 to 36	3	98.2	97.5

More frequent, intense wildfires may shift the population structure toward taller, older adults with fewer opportunities for plant recruitment in 1.0 percent of the YUBR South population. The areas with the potential shifts in population structure will likely be located on the southwestern perimeter of the current mapped distribution along the urban-wildland interface. This may lead to a contraction of the range along the edge of the distribution in those areas. However, not all trees will be lost along this perimeter and a large percentage of the range would remain unaffected. So some decline in resiliency may occur due to this stressor in the future but a large expanse of habitat supporting a high number of individuals should remain.

A 1–2°C increase in maximum temperatures is within our understanding of the current maximum temperature tolerance for the species. Average winter temperature increases between 1–1.5°C are projected for some regions and could lead to less optimal growth and recruitment. Adaptations to increasing maximum temperatures could include migration to cooler or higher elevation areas of the desert. So some decline in resiliency may occur due to this stressor in the future but a large expanse of habitat supporting a high number of individuals should remain.

Habitat loss will reduce the amount of space available for Joshua tree individual resource needs, which could result in a decline in resilience. However, because *Yucca brevifolia* currently occurs in areas with low density residential, the predicted future loss of habitat due to an increase in low density residential development may not lead to a complete loss of resource needs necessary to maintain population resiliency. Currently, about 64 percent of the development within the YUBR South range is classified as low intensity (NCLD GIS data). We anticipate this type of development pattern will continue so much of the predicted 21.7 percent habitat loss will support Joshua trees but likely at lower densities. However, this type of development pattern could result in a more fragmented regional population, which could reduce future genetic exchange and connectivity in YUBR South. So some decline in resiliency may occur due to this stressor in the future but a large expanse of habitat supporting a high number of individuals should remain.

Though information is limiting, we anticipate that all three stressors could also lead to a loss of *Tegeticula synthetica* moths through direct mortality and reduced moth population due to the loss of individual *Yucca brevifolia* plants.

Combined, these three stressors will result in the disruption or loss of individual habitat resource needs that could reduce seedling establishment and survival rates, reduce the possibility of range expansion or dispersal opportunities, and reduce population abundance in the future, which may result in some loss of resiliency in this population. However, because YUBR South is distributed over a large, ecologically diverse landscape and includes 1.2 million ac (476,332 ha) of area with management/conservation potential, very high numbers of individuals should continue to persist across a large land area through the 21st century.

In general, under Scenario II, 1.4 percent of the current mapped distribution in this population may experience larger, more frequent fires; a higher increase in mean winter and summer temperatures; no change in summer precipitation; an increase in cool season precipitation; and a 41.6 percent habitat loss. The amount of conservation/management potential and the number of ecoregions represented does not change (Table 11).

More frequent, intense wildfires may shift the population structure toward taller, older adults with fewer opportunities for plant recruitment in 1.4 percent of the YUBR South population. A similar conclusion to the one above for Scenario I with regards to altered fire regimes can be made for Scenario II so it is unlikely this scenario would lead to an increased decline in resiliency.

A 3°C increase in maximum temperatures may result in a reduced distribution via reduced recruitment rates. However, finer-scale modelling that identified local adaptations indicated there may be some areas of climate-change refugia (e.g., steep north facing slopes and higher elevations) so we assume that even in the more southern parts of the range, Joshua trees will continue to persist in these areas but with more disjunct, smaller local populations. Average winter temperature increases between 3–5°C are projected and could lead to less optimal growth and recruitment but some expansion to higher elevations may be possible. So we anticipate some decline in resiliency may occur due to this stressor in the future but a large expanse of habitat supporting a high number of individuals should remain.

Habitat loss will reduce the amount of space available for Joshua tree individual resource needs, which could result in a decline in resilience. However, because *Yucca brevifolia* currently occurs in areas with low density residential, the predicted future loss of habitat due to an increase in low density residential development may not lead to a complete loss of resource needs necessary to maintain population resiliency. Currently, about 64 percent of the development within the YUBR South range is classified as low intensity (NCLD GIS data). We anticipate this type of urban development pattern will continue so over half of the predicted 43.2 percent habitat loss should continue to support Joshua trees but at lower densities. This type of development pattern may result in a more fragmented regional population, which could reduce future genetic exchange and connectivity in YUBR South. So some decline in resiliency may occur due to this stressor in the future.

Combined, these three stressors may result in a greater disruption or loss of individual habitat resource needs that could reduce seedling establishment and survival rates, reduce the possibility of range expansion or dispersal opportunities, and reduce population abundance in the future, which may result in a loss of resiliency in this population. However, because YUBR South is distributed over such a large geographic area and includes 1.2 million ac (476,332 ha) of area with management/conservation potential, very high numbers of individuals should persist on the landscape through the end of the century.

YUBR North

In general, under Scenario I, 3.9 percent of the current mapped distribution in this population will experience larger, more frequent fires; an increase between 2–3°C in both mean summer and winter temperatures; no change in summer precipitation; an increase in cool season precipitation; and a less than 1 percent loss of habitat. The amount of conservation/management potential and the number of ecoregions represented does not change (Table 11).

Though information is limiting, we anticipate that all three stressors could also lead to a loss of *Tegeticula synthetica* moths through direct mortality and reduced moth population due to the loss of individual *Yucca brevifolia* plants.

Combined, these stressors may result in the disruption or loss of individual habitat resource needs that could reduce seedling establishment and survival rates, reduce the possibility of range expansion or dispersal opportunities, and reduce population abundance. However, we do not anticipate a reduction in resiliency to YUBR North under Scenario I based on the small amount of disturbance from altered fire regimes and direct habitat loss. We also do not anticipate of loss of resiliency to YUBR North due to increases in temperature since this population is distributed in the cooler northern regions of the desert. YUBR North will likely continue to be distributed over a large geographic area and include 739,444 ac (299,242 ha) of area with management/conservation potential, so very high numbers of individuals should continue to persist across the landscape through the end of the century.

In general, under Scenario II, 8.7 percent of the current mapped distribution in this population will experience larger, more intense, and more frequent fires; an increase of 3°C in mean summer temperatures and a 2.5–5.5°C increase in mean winter temperatures; some decrease in summer precipitation over half of the range and cool season precipitation will increase; and less than 1 percent loss of habitat (Table 11).

Combined, these stressors may result in the disruption or loss of individual habitat resource needs that could reduce seedling establishment and survival rates, reduce the possibility of range expansion or dispersal opportunities, and reduce population abundance. However, we do not anticipate a reduction of resiliency in YUBR North under Scenario II based on the small amount of disturbance from altered fire regimes and direct habitat loss. Increases in minimum temperatures may limit or reduce distribution assuming increasing winter temperatures result in reduced recruitment rates. However, opportunities for a northern expansion may exist and YUBR North will continue to include 739,444 ac (299,242 ha) of area with management/conservation potential, so very high numbers of individuals should continue to persist on the landscape through the end of the century.

Overall *Yucca brevifolia* Future Resiliency, Redundancy, and Representation

Our goal in the assessment was to describe the viability of *Yucca brevifolia* in a manner that will describe the needs of the species in terms of resiliency, redundancy, and representation. We used the best available information to determine the current conditions and forecast the likely future conditions of *Y. brevifolia*. We have identified and considered what *Y. brevifolia* need (Sections 4 and 5) for viability and the current condition of those needs, and we reviewed the risk factors that are driving the current (Section 6) and future (Section 7) conditions of the species. We considered two potential scenarios that outline varying levels of impacts for each species. The stressors chosen for our analysis are those that we have determined may drive species viability into the future. We now consider the species future viability by summarizing our future forecasts based on the concepts of resiliency, redundancy, and representation to describe the future viability of *Y. brevifolia*.

Yucca brevifolia is distributed in two regional populations mostly across the western Mojave Desert and within an area of approximately 5.7 million ac (2.3 million ha), 5.1 million ac (2.1 million ha) of which contains habitat to support resource needs. Based on the habitat elements discussed above in the Current Condition Section, both populations currently have a high capacity to withstand or recover from stochastic disturbance events due to the large distribution, high number of individuals, ecological diversity, and amount of management/conservation area that limits habitat disturbance and provides more intact ecosystems.

Resiliency

Future stressors affecting large portions of the range-wide distribution would likely include increasing temperatures, both minimum and maximum, which could result in a decline in current population resiliency. Under future Scenario I both populations would persist on the landscape through the 21st century with some loss of resiliency to both populations. Synergies among the stressors evaluated could exacerbate potential future effects on the two populations. We anticipate Scenario II would result in a greater reduction in population resiliency for YUBR

South because of habitat loss; resiliency in YUBR North would likely remain high if altered fire regimes are confined to a small percentage of the range.

Redundancy

We consider the current species redundancy to be high since there is a large amount of area currently supporting individual plants and the number of individuals across the range could be in the millions. Adverse impacts from threats are spread across a 5 million-acre area so it is not likely that catastrophic events, such as wildfire, would lead to mortality of all individuals in the population. However, increasing temperatures could affect large areas of the current mapped distribution in the future resulting in loss of distribution and connectivity and may lead to a decline in species redundancy. Future species redundancy could decline from current levels in areas with increasing minimum temperatures as a result of reduced seedling establishment and survival, so areas in YUBR South that are currently warmer than YUBR North may experience lower recruitment and ultimately a southern range contraction, similar to what was experienced over the course of about 8,000 years during the Holocene warming period. But areas of refugia could support smaller populations and the species is likely to persist. *Yucca brevifolia* may have the ability to colonize areas north of its current distribution, which could offset a southern range contraction. If this occurs, redundancy would remain high (assuming their pollinators also persist), since populations would continue to include high numbers of individuals distributed across a large land area. Regardless of whether a northern expansion occurs, we anticipate the species will continue to have very high numbers of individuals distributed across regional landscape-scale areas through the 21st century since about 2 million ac (809,371 ha) of the mapped distribution is under management/conservation designations that support more intact ecosystems.

Representation

Current species representation is high as individuals occupy relatively diverse areas within the Mojave and Great Basin Deserts that encompass variation in elevation, soil type, temperature, rainfall, and vegetation communities. While ecoregion diversity does not decline under future Habitat Loss scenarios, altered fire regimes and increasing temperatures could affect large areas of the current mapped distribution in the future causing a decline in connectivity and ecological diversity, leading to a future decline in species representation. However, because of the large range-wide distribution and habitat diversity we anticipate there will be areas of refugia throughout the range where the species will persist. The species may also have the ability to colonize areas north of its current distribution or higher elevations with cooler winter temperatures within its current distribution. Additionally, because about 2 million ac (809,371 ha) of the mapped distribution is under management/conservation designations that support more intact ecosystems we anticipate the species will continue to have high numbers of individuals distributed across an ecologically diverse landscape through the 21st century.

Potential Stressors and Future Effects to *Yucca jaegeriana* Populations.

A future stressor analysis for this species has the same challenges identified for *Yucca brevifolia* because of its relatively long life span (~200 years) and long time to sexual maturity (up to 30 years). Therefore, we evaluated how stressors through the end of the 21st century may affect vital rates such as seedling establishment and recruitment, adult survival, and pollinator abundance needed for population growth and thus future viability (See Figure 17).

In our *Yucca jaegeriana* future stressor analysis, we included the same current stressors as we did for *Y. brevifolia*, which include altered fire regimes and invasive plants, climate change, and habitat loss that have the potential to affect Joshua tree resilience at the population level. We also considered that these stressors may act synergistically to create an effect greater than the sum of their separate effects (Table 10).

Altered Fire Regimes and Invasive Annual Grasses

The above current condition assessment concluded that fire regimes across the range of *Yucca jaegeriana* have likely increased in frequency and intensity over recent decades, and that this broader altered regime has been largely driven by the proliferation of invasive annual grasses which act as fine fuels and connect vegetation previously less connected. Recent fires have predominantly occurred within mid-elevation areas, where a large proportion of the *Y. jaegeriana* range occurs. *Yucca jaegeriana* may be particularly vulnerable to fire because evolution and adaption by native Mojave Desert plant species in general have not been largely influenced by fire. We anticipate that fires with increasing intensity (i.e., increasing energy output) due to invasive grass proliferation would result in increased fire severity, with potential broader scale ecosystem effects such as loss of above- and below-ground soil organic matter, increased soil erosion, and longer recovery times for burned areas (Keeley 2009, p. 118).

Direct effects to *Yucca jaegeriana* from fire include immediate individual mortality, particularly to smaller stature plants [less than 1 m (3.3 ft) in height], and increased mortality rate and reduced survivorship within populations over time. Young plants are most vulnerable to fire because they have their active meristems close to the ground. Increased fire frequency and burn severity could drive *Y. jaegeriana* population structure toward older and larger size classes in burned areas, because smaller plants are more susceptible to fire and because germination and recruitment of new plants relies on avoidance of fire. Other indirect effects to *Y. jaegeriana* from fire include degraded seed bank, loss of aboveground vegetation that could serve as nurse plants to seedlings, and alteration in seed-caching rodent dynamics within *Y. jaegeriana* stands. Invasive annual species also tend to be more competitive at re-colonizing burned areas, increasing future fire potential. In general, altered fire regimes could degrade these habitat resource needs within the current distribution of *Y. jaegeriana* in the future.

Due to the limited information available on population distribution patterns and abundance in each population, estimating the potential future impacts of altered fire regimes on population resiliency is difficult. What we can more reliably predict is how particular resource needs are related to future effects from fire and which demographic needs could be influenced (Figure 26).

As earlier illustrated in Figure 21, current fire return intervals across *Yucca jaegeriana* populations are generally greater than 300 and 500 years. Because of the close coupling of invasive grasses acting as fine fuels resulting in larger and more frequent fires within the Mojave Desert, we used data from the BLM’s Mojave Basin and Range Rapid Ecoregional Assessment (Comer *et al*. 2013, p. 79) that models the potential abundance of invasive grass within *Y. brevifolia* populations to assist in projecting future habitat conditions for *Y. jaegeriana*

(Table 12). The model was derived from field data and the following landscape variables: elevation, aspect, distance to fire, geology, distance to hydric soils, distance to intermittent streams, landform, ombrotype [a measure of ombroclimatic (moisture) gradients], soil pH, density of primary roads, density of secondary/local roads, percent sandy soil, slope, and thermotype [a measure of thermoclimatic (temperature) gradients].

Future Scenarios – Altered Fire Regimes and Invasive Annual Grasses

Scenario I – All Populations

Under Scenario I, we considered habitat areas that are projected to have 25–45 percent invasive grass cover are more vulnerable to an altered fire regime consisting of larger, more frequent fires with higher burn severity. This cover category includes approximately 2.4 percent of the YUJA Central, 7.0 percent of the YUJA North, and 0.1percent the YUJA East current mapped distributions. We have no data for 78.8 percent of the YUJA East population.

Table 12: Risk of Invasive Grass Potential for Yucca jaegeriana populations

***Y. jaegeriana* Central**	
Greater than 45%	2.3 percent
25% - 45% Cover	2.4 percent
15% - 25% Cover	0.3 percent
5% - 15% Cover	1.3 percent
<5% Cover	53.8 percent
No/Low	38.4 percent
No Data	1.6 percent
***Y. jaegeriana* North**	
Greater than 45%	21.2 percent
25% - 45% Cover	7.0 percent
15% - 25% Cover	2.3 percent
5% - 15% Cover	2.0 percent
<5% Cover	32.4 percent
No/Low	32.4 percent
No Data	2.2 percent
***Y. jaegeriana* East**	
25% - 45% Cover	0.1 percent
15% - 25% Cover	0.02 percent
<5% Cover	5.8 percent
No/Low	15.2 percent
No Data	78.8 percent

Under this scenario we anticipate a longer-term impact to *Yucca jaegeriana* population as fire frequency increases and results in diminished recruitment and reduction in population abundance in a small percentage of the range but we lack information to provide a reasonable prediction on the timing of this potential longer-term effect. Finally, we anticipate that fires could lead to the loss of moths that pollinate *Y. jaegeriana* (*Tegeticula antithetica*) through direct mortality and reduced moth population due to the loss of *Y. jaegeriana* plants.

Scenario II – All Populations

Under Scenario II, we considered that habitat areas that are projected to have 15–45 percent invasive grass cover are more vulnerable to an altered fire regime consisting of larger, more frequent fires with higher burn severity. This cover category includes approximately 2.7 percent of the YUJA Central, 9.3 percent of the YUJA North, and at least 0.12 percent of the YUJA East population.

Under this scenario we anticipate more habitat within the *Yucca jaegeriana* current mapped distribution will experience a longer-term impact as fire frequency increases and results in diminished recruitment and reduction in population abundance in a small percentage of the range but we lack information to provide a reasonable prediction on the timing of this potential longer-term effect. Finally, we anticipate that fires could lead to the loss of moths that pollinate *Yucca jaegeriana* (*Tegeticula antithetica*) through direct mortality and reduced moth population due to the loss of *Y. jaegeriana* plants.

Climate Trends

Future effects from climate change on populations of *Yucca jaegeriana* are the same as *Y. brevifolia*. Refer to the section above under Climate Trends – *Yucca Brevifolia* for a discussion on potential future climate conditions and how those may influence *Y. jaegeriana* population resiliency.

Future Scenarios – Climate Change

YUJA Central

Under scenario I, mean summer temperatures are projected to increase by 1–2°C in areas within the current mapped distribution. Mean winter temperatures are predicted to increase by 1–1.5°C in approximately half of the areas and stay the same in the other half. Summer precipitation is projected to roughly stay the same for about half of the area and slightly increase (up to 5 mm) for the remaining half. Cool season precipitation is projected to increase in all areas from 2–20 mm.

Under scenario II, mean summer temperatures are projected to increase by 3°C in most areas, with a 4°C increase predicted for a smaller area within the current mapped distribution and mean winter temperatures are predicted to increase by 3.5–5.5°C. Summer precipitation is again predicted to stay the same for approximately half of the area, with a 5–10 mm increase predicted for the other half of the area. Cool season precipitation is projected to increase in all areas up to 20 mm.

YUJA North

Under scenario I, mean summer temperatures are projected to increase 2–3°C in areas throughout the current mapped distribution and mean winter temperatures are predicted to increase by 1–1.5°C. Summer precipitation is projected to roughly stay the same for most of the area, with a 2 mm reduction forecast for a very small area and increases up to 2.5 mm predicted for another small part of the area. Cool season precipitation is projected to increase in all areas from 2–20 mm.

Under scenario II, mean summer temperatures are projected to increase 3–6°C throughout areas within the current mapped distribution and mean winter temperatures are predicted to increase by 3–4°C. Summer precipitation is projected to stay the same for most of the area while a 1.5–4.5 mm increase in precipitation is predicted for a very small portion of the remaining area. Cool season precipitation is projected to increase in all areas from 2–14 mm.

YUJA East

Under scenario I, mean summer temperatures are projected to increase by 1–2°C in areas within the current mapped distribution and mean winter temperatures are predicted to increase by 1–1.5°C. Summer precipitation is projected to increase in all areas from 2–20 mm. Cool season precipitation is also expected to increase in all areas, although a slightly smaller increase between 2–15 mm.

Under scenario II, mean summer temperatures are projected to increase by 4–5°C in most areas, with a 2°C increase predicted for a smaller area within the current mapped distribution and mean winter temperatures are predicted to increase by 3.5–4.5°C. Summer precipitation is projected to increase in all areas from 5–20 mm. Cool season precipitation is also projected to increase, although a slightly smaller increase between 2–15 mm.

Habitat Loss

The above current condition assessment concluded that across the range, habitat loss may include urban expansion and development, military installation expansion and training activities, renewable energy development, grazing, and OHV activity. Future habitat loss could degrade habitat resource needs within the current distribution of Joshua tree (Figure 24) and result in a decline in distribution. Below we discuss the potential future habitat loss that may occur for *Yucca jaegeriana* and measures currently in place that may limit such loss. We assume that future grazing and OHV activity will not influence future population resiliency based on available information.

Urban Expansion and Development

We used the ICLUS modelling tool to forecast housing density growth to the year 2095 within the current mapped distribution for *Yucca jaegeriana* based on two different emission scenarios (EPA 2009, entire). Future urban expansion patterns will likely reflect current trends with concentrated growth across existing urban areas in the western Mojave Desert such as surrounding the cities of Las Vegas, Pahrump, and Henderson, Nevada. This loss of habitat could affect resource needs, reduce the distribution, and lead to a reduction in population resiliency. We anticipate that the large proportion of lands under federal management and the existing state and city ordinances (Table 3) that are in place to protect *Y. jaegeriana* from harvesting will continue, which could help to lessen the effects of habitat loss due to urban expansion and development.

Military Activities

Currently, about 5 percent of the YUJA North population overlaps with the Nellis Air Force Base, and 3 percent of the YUJA Central population extends into the Fort Irwin National

Training Center. Current public law allows the Air Force to use a portion of the Desert National Wildlife Refuge Complex's Desert National Wildlife Range (DNWR) for military activities conducted on the NTTR on Nellis Air Force Base. However, there are current restrictions the Air Force and the Service are observing in proposed wilderness areas that are located on NTTR and DNWR lands co-managed by the Air Force and the Service. The DNWR encompasses more than 1.6 million ac (647,497 ha) of land with about half of those lands, approximately 842,254 ac (340,848 ha), overlapping with the NTTR. Of these acres, about 350,000 (141,639 ha) are within the current mapped distribution for YUJA North. In the future, management for this area could be re-classified for military training purposes, which could lead to an additional 17 percent of habitat within the current mapped distribution used for military training activities in the YUJA North population.

These installations have developed INRMPs that incorporate avoidance and minimization measures that could reduce individual mortality of *Yucca jaegeriana* and disturbance of their habitat (see above). These plans also have the potential to implement management activities to improve our understanding of future *Y. jaegeriana* demographic trends and population resiliency.

Renewable Energy Development

Renewable energy development can degrade and potentially remove *Yucca jaegeriana* habitat. There are no areas within the current mapped distribution that occur on Development Focus Areas designated under the DRECP. Under the Solar PEIS and BLM's current pending lease areas there are approximately 21,881 ac (8,855 ha) that overlap with the current mapped distribution. These areas comprise about 0.35 percent of the current mapped distribution. Information on acreage projections for future development of renewable energy projects on non-federal lands is unavailable but we assume any future loss to Joshua tree individuals and habitat associated with renewable energy development on private lands will be reflected in the ICLUS projections for future urban development.

Land Management and Conservation

Areas within the current mapped distribution for *Yucca jaegeriana* that are located within NPS units; BLM ACEC's, NLCS lands, and National Monuments; and other State wilderness designations have management/conservation potential not afforded areas outside of these designations. These areas limit habitat disturbance and provide more intact ecosystems and may provide areas that support more resilient local populations. We anticipate that in the future, these areas will continue to have protections and be managed to limit disturbance. Within the populations for *Y. jaegeriana*, YUJA Central includes 55.3 percent of the mapped distribution in these areas, YUJA North includes 57.8 percent, and YUJA East has 23.5 percent, for a total of 3.2 million ac (1.3 million ha) that provide more intact ecosystems. Synergistic effects from other stressors could confound protections afforded plants in these areas if increasing temperatures and longer droughts or more frequent and intense wildfires result in negative population growth in these managed and/or conserved areas.

Future Scenarios – Habitat Loss

Under Scenario I, 51,409ac (20,805 ha) of the current mapped distribution will be lost to urban development and expansion based on projections in the ICLUS database. Renewable energy development continues and acres are built-out according to those described in the Solar PEIS and BLM pending land leases. This scenario results in an overall loss of 73,290 ac (29,659 ha) of the mapped distribution by 2095 (Table 13, Figure 35). Urban development and expansion is primarily responsible for future increases in habitat loss. This represents a 1.2 percent reduction of *Yucca jaegeriana* suitable habitat supporting adequate soils, seed bank, nurse plants, yucca moths, and seed dispersal and caching.

Under Scenario II, 51,409 ac (20,805 ha) of the current mapped distribution will be lost to urban development and expansion based on projections in the ICLUS model based on scenario A2. Renewable energy development continues and acres are built-out according to those described in the Solar PEIS and BLM pending land leases. The 350,000 ac (141,640 ha) within the DNWR in YUJA North is re-classified for military training purposes. This scenario results in an overall loss of 870,781 ac (352,393 ha) of the mapped distribution by 2095 (Table 13, Figure 35). Military expansion and training is primarily responsible for future increases in habitat loss. This represents a 13.8 percent reduction of *Yucca jaegeriana* suitable habitat supporting adequate soils, seed bank, nurse plants, yucca moths, and seed dispersal and caching.

Table 13: *Yucca jaegeriana* Future Habitat Loss by Scenario

Scenario I					
	Mapped Suitable Habitat (ac)	**Mapped Suitable Habitat (ha)**	**Potential Habitat loss (ac)**	**Potential Habitat loss (ha)**	**Potential Percent Loss**
YUJA Central	2,997,787	1,213,162	62,915	25,461	2.1%
YUJA North	2,035,901	823,901	3,344	1,353	0.2%
YUJA East	1,280,820	518,330	7,031	2,845	0.5%
Species Total	**6,314,508**	**2,555,393**	**73,290**	**29,659**	**1.2%**
Scenario II					
YUJA Central	2,997,787	1,213,162	311,934	126,235	10.4%
YUJA North	2,035,901	823,901	363,059	146,925	17.8%
YUJA East	1,280,820	518,330	195,788	79,233	15.3%
Species Total	**6,314,508**	**2,555,393**	**870,781**	**352,393**	**13.8%**

Summary of Potential Future Conditions on Yucca jaegeriana Population Resiliency

YUJA Central

In general, under Scenario I, 2.4 percent of the current mapped distribution in this population will experience larger, more frequent fires; an increase between 1–2°C in both mean summer and winter temperatures; a small increase in both summer and cool season precipitation; and a

2.1 percent loss of habitat by the end of the century. The amount of management/conservation potential and the number of ecoregions represented does not change (Table 14).

More frequent, intense wildfires may shift the population structure toward taller, older adults with fewer opportunities for plant recruitment in a small percent of the YUJA Central population. This may lead to a decline in density, especially of younger age-classes. However, not all trees will be lost from an altered fire regime within this population. Some decline in resiliency may occur due to this stressor in the future but a large expanse of habitat supporting a high number of individuals would remain. We do not anticipate a loss of resiliency to this population from the shifts in temperature and precipitation patterns predicted under Scenario I. We also do not anticipate a loss of resiliency due to the small amount of habitat loss.

Though information is limiting, we anticipate that all three stressors could also lead to a loss of *Tegeticula antithetica* moths, through direct mortality and reduced moth population due to the loss of individual *Yucca jaegeriana* plants.

Combined, these three stressors will result in disruption or loss of individual habitat resource needs that could reduce seedling establishment and survival, reduce the possibility of range expansion or dispersal opportunities, and reduce population abundance in the future, which may result in a loss of resiliency in this population. However, because YUJA Central is distributed over such a large geographic area and includes 1.7 million ac (687,793 ha) of area with management/conservation potential, high numbers of individuals should persist across a large geographic area through the end of the 21st century.

In general, under Scenario II, 2.7 percent of the current mapped distribution in this population will experience larger, more frequent fires; a larger increase in mean winter and summer temperatures; a small increase in summer and cool season precipitation; and a 10.4 percent loss of habitat through the end of the century. The amount of management/conservation potential and the number of ecoregions represented does not change (Table 14).

More frequent, intense wildfires may shift the population structure toward taller, older adults with fewer opportunities for plant recruitment. The same effects described under Scenario I would occur under this scenario but with more of the population affected. If the population structure shifts and density declines in younger plants, then population resiliency may decline.

A 3°C increase in maximum temperatures may result in a reduced distribution via reduced recruitment rates. However, finer-scale modelling that identified local adaptations indicated there may be some areas of climate-change refugia so we assume that Joshua trees will continue to persist but with more disjunct local populations. Average winter temperature increases between 3.5–5.5°C are projected for some regions and could lead to less optimal growth and recruitment. A northern expansion is not possible for this population, so a decline in the distribution may occur. Therefore, some decline in resiliency may occur due to this stressor in the future but a large expanse of habitat supporting a high number of individuals would remain.

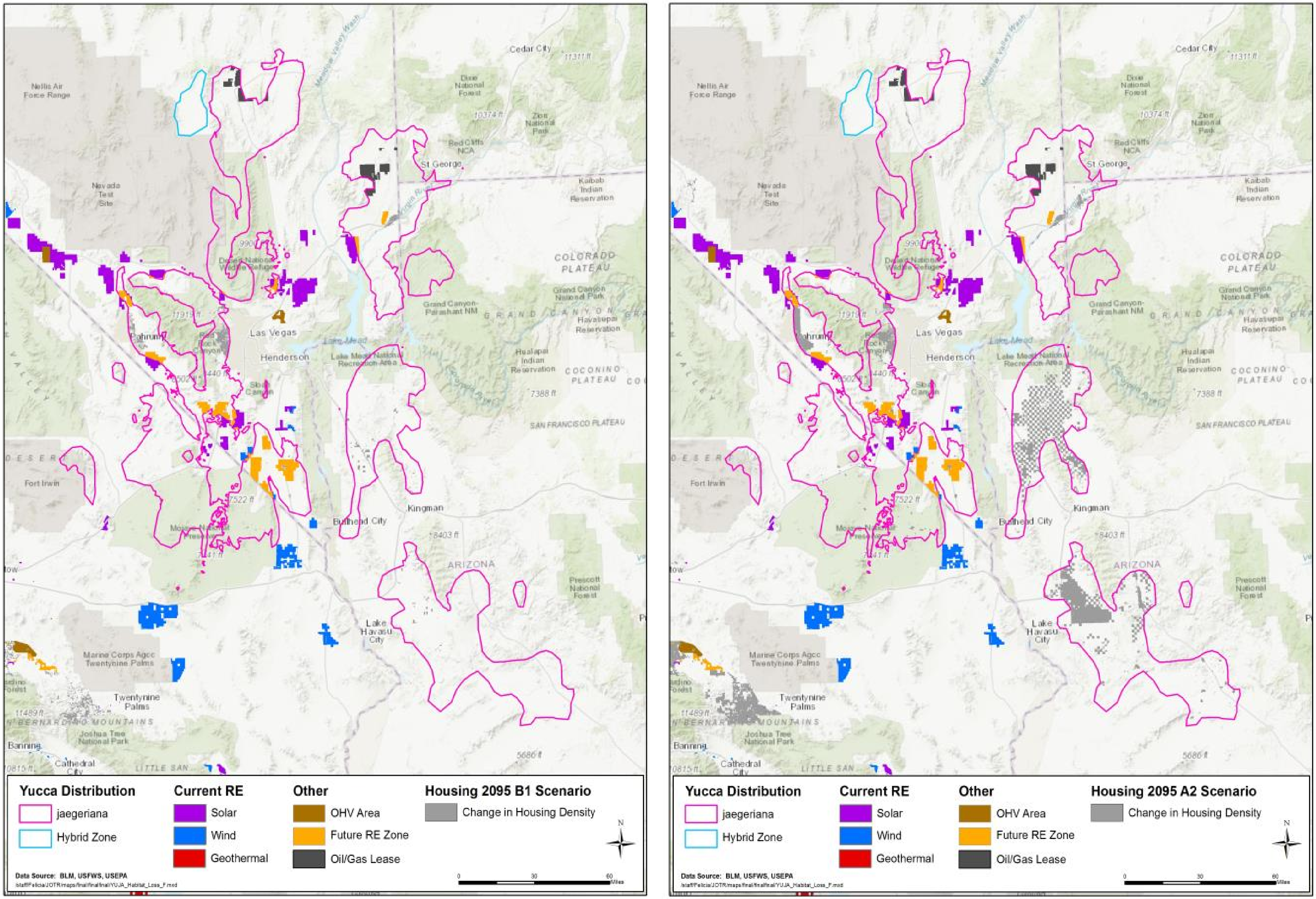


Figure 35: Habitat Loss*, Yucca Jaegeriana*. Scenario 1 (Left) and Scenario II (right)

Table 14: *Yucca jaegeriana* Future Scenario Summary

Population	Percent Future Altered Fire Regime	Current Mean Low Temp Range (C)	Future Mean Low Temp Increase (C)	Current Mean High Temp Range (C)	Future Mean High Temp Increase (C)	Current Percent Suitable Habitat	Future Percent Suitable Habitat
Scenario I							
YUJA Central	2.4	-5.3 to 5.9	1 to 1.5	27 to 40	1 to 2	97.6	95.5
YUJA North	7.0	-6.5 to 4.2	1 to 1.5	26-40	2 to 3	98.4	98.2
YUJA East	0.1	-1 to 5.5	1 to 1.5	30 to 40	1 to 2	99.3	98.8
Scenario II							
YUJA Central	2.7	-5.3 to 5.9	3.5 to 5.5	27 to 40	3	97.6	87.2
YUJA North	9.3	-6.5 to 4.2	3 to 4	26 to 40	3 to 6	98.4	80.6
YUJA East	0.12	-1 to 5.5	3.5 to 4.5	30 to 40	4 to 5	99.3	84.0

Combined, these three stressors may result in greater disruption or loss of individual habitat resource needs that could reduce seedling establishment and survival, reduce the possibility of range expansion or dispersal opportunities, and reduce population abundance in the future, which may result in a loss of resiliency in this population. However, because YUJA Central is distributed over such a large geographic area and includes 1.7 million ac (687,793ha) of area with management/conservation potential, high numbers of individuals should continue to persist on the landscape through the end of the 21st century.

YUJA North

In general, under Scenario I, 7.0 percent of the current mapped distribution in this population will experience larger, more frequent fires; an increase between 2–3°C in mean summer and 1–1.5°C increase in winter temperatures; no change in summer precipitation; a slight increase in cool season precipitation; and a less than 1 percent loss of habitat by the end of the century. The amount of management/conservation potential and the number of ecoregions represented does not change (Table 14).

More frequent, intense wildfires may shift the population structure toward taller, older adults with fewer opportunities for plant recruitment. The areas with the potential shifts in population structure are located on the northern edge of the current mapped distribution. This may lead to a contraction of the range along the edge of the distribution in those areas. However, not all trees will be lost and a large percentage of the mapped distribution would remain unaffected. So some decline in resiliency may occur due to this stressor in the future but a large expanse of habitat supporting a high number of individuals should remain under this scenario.

We do not anticipate a loss of resiliency from the shifts in temperature and precipitation patterns predicted under Scenario I. It is unlikely there will be a loss to resiliency from habitat loss based on the relatively small amount of the current mapped distribution affected.

Though information is limiting, we anticipate that all three stressors could also lead to a loss of *Tegeticula antithetica* moths, through direct mortality and reduced moth population due to the loss of individual *Yucca jaegeriana* plants.

Combined, these three stressors will result in a greater disruption or loss of individual habitat resource needs that could reduce seedling establishment and survival, reduce the possibility of range expansion or dispersal opportunities, and reduce population abundance in the future, which may result in a loss of resiliency in this population. However, because YUJA North is distributed over such a large geographic area and includes 1.1 million ac (483,726 ha) of area with management/conservation potential, high numbers of individuals should persist across the landscape through the end of the 21st century.

In general, under Scenario II, 9.3 percent of the current mapped distribution in this population will experience larger, more frequent fires; a larger percent increase in mean winter and summer temperatures; a small increase in summer precipitation; an increase in cool season precipitation; and a 17.8 percent loss of habitat through the end of the century. The amount of management/conservation potential and the number of ecoregions represented does not change (Table 14).

More frequent, intense wildfires may shift the population structure toward taller, older adults with fewer opportunities for plant recruitment. The same effects described under Scenario I would occur under this scenario but with more of the population affected. If the population structure shifts and density declines in younger plants, then population resiliency may decline.

A >3°C increase in maximum temperatures may result in a reduced distribution via reduced recruitment rates. However, finer-scale modelling that identified local adaptations indicated there may be some areas of climate-change refugia so we assume that Joshua trees will continue to persist but maybe with more disjunct local populations. Average winter temperature increases between 3–4°C are projected for some regions and could lead to less optimal growth and recruitment. A northern expansion may be possible for this population, so a decline in the distribution is not anticipated. However, some decline in resiliency may occur due to a decline in recruitment in the future but a large expanse of habitat supporting a high number of individuals should remain.

Combined, these three stressors will result in greater disruption or loss of individual habitat resource needs that could reduce seedling establishment and survival, reduce the possibility of range expansion or dispersal opportunities, and reduce population abundance in the future, which may result in a loss of resiliency in this population. However, because YUJA North is distributed over such a large geographic area and includes 1.1 million ac (483,726 ha) of area with management/conservation potential, large numbers of individuals should persist through the end of the 21st century.

YUJA East

In general, under Scenario I, 0.1 percent of the current mapped distribution in this population will experience larger, more frequent fires; a 1–2°C increase in mean winter and summer temperatures; an increase in both summer and cool season precipitation; and a less than 1 percent loss of habitat through the end of the century. The amount of management/conservation potential and the number of ecoregions represented does not change (Table 14).

More frequent, intense wildfires may shift the population structure toward taller, older adults with fewer opportunities for plant recruitment for a very small area within the current mapped distribution where information on invasive grass cover is available. We lack information to evaluate whether a change in fire regimes will lead to a decline in resiliency for 78.8 percent of this population.

We do not anticipate a loss of resiliency from the shifts in temperature and precipitation patterns predicted under Scenario I. It is also unlikely there will be a loss to resiliency from habitat loss based on the relatively small amount of the current mapped distribution affected.

Though information is limiting, we anticipate that all three stressors could also lead to a loss of *Tegeticula antithetica* moths, through direct mortality and reduced moth population due to the future loss of individual *Yucca jaegeriana* plants.

Combined, these three stressors will result in disruption or loss of individual habitat resource needs that could reduce seedling establishment and survival rates, reduce the possibility of range expansion or dispersal opportunities, and reduce population abundance in the future, which may result in a loss of resiliency in this population. However, because YUJA East is distributed over such a large geographic area and includes 302,612 ac (122,463 ha) of area with management/conservation potential, high numbers of individuals should persist up through the end of the 21st century.

In general, under Scenario II, 0.14 percent of the current mapped distribution in this population will experience larger, more frequent fires; a larger increase in mean summer and winter temperatures; an increase in both summer and cool season precipitation; and a 15.3 percent loss of habitat through the end of the century. The amount of management/conservation potential and the number of ecoregions represented does not change (Table 14).

A >4°C increase in maximum temperatures may result in a reduced distribution via reduced recruitment rates. However, finer-scale modelling that identified local adaptations indicated there may be some areas of climate-change refugia so we assume that Joshua trees will continue to persist but maybe with more disjunct local populations. Average winter temperature increases between 3–4°C are projected for some regions and could lead to less optimal growth and recruitment. A northern expansion may not be possible for this population, so a reduction in the distribution may occur. Therefore, some decline in resiliency may occur due to a decline in recruitment in the future but a large expanse of habitat supporting a high number of individuals should remain.

Combined, these three stressors will result in disruption or loss of individual habitat resource needs that could reduce seedling establishment and survival rates, reduce the possibility of range expansion or dispersal opportunities, and reduce population abundance in the future, which may result in a loss of resiliency in this population. However, because YUJA East is distributed over such a large geographic area and includes 302,612 ac (122,463 ha) of area with management/conservation potential, high numbers of individuals should persist through the end of the 21st century.

Summary of Potential Future Conditions on Hybrid Zone Population Resiliency

Almost all the land within the hybrid zone is managed by the BLM. We anticipate there will be no significant change to current fire regimes and no significant habitat loss in the hybrid zone, so a loss to current resiliency is not anticipated. We also do not anticipate a loss of resiliency from the shifts in temperature and precipitation patterns predicted under Scenario I.

Under Scenario II, a >3°C increase in maximum temperatures may result in a reduced distribution via reduced recruitment rates. However, finer-scale modelling that identified local adaptations indicated there may be some areas of climate-change refugia so we assume that Joshua trees will continue to persist in the Hybrid Zone. Average winter temperature increases between 3–4°C are projected and could lead to less optimal growth and recruitment. A northern expansion may be possible for this population, so a decline in the distribution is not anticipated. However, some decline in resiliency may occur due to a decline in recruitment in the future.

Overall *Yucca jaegeriana* Future Resiliency, Redundancy, and Representation

Our goal in the assessment was to describe the viability of *Yucca jaegeriana* in a manner that will describe the needs of the species in terms of resiliency, redundancy, and representation. We used the best available information to determine the current conditions and forecast the likely future conditions of *Y. jaegeriana*. We have identified and considered what *Y. jaegeriana* needs (Sections 4 and 5) for viability and the current condition of those needs (Section 6), and we reviewed the risk factors that are driving the current (Section 6) and future conditions (Section 7) of the species. We considered two potential scenarios which outline varying levels of impacts for each species. The stressors chosen for our analysis are those that we have determined may drive species viability into the future. We now consider the species future viability by summarizing our future forecasts based on the concepts of resiliency, redundancy, and representation to describe the future viability of *Y. jaegeriana*.

Yucca jaegeriana

Yucca jaegeriana is distributed in three populations across the eastern Mojave, southern Great Basin, and western Sonoran Deserts within an area of approximately 6.4 million ac (2.6 million ha), 6.3 million ac (2.5 million ha) of which contains habitat to support resource needs. Based on the habitat elements discussed above, all three *Y. jaegeriana* populations have a high level of resiliency based on the large distribution, high number of individuals, ecological diversity, and amount of management/conservation area that limits habitat disturbance and provides more intact ecosystems.

Resiliency

Future stressors affecting large portions of the range-wide distribution would likely include increasing temperatures, both minimum and maximum, which could result in a decline in current population resiliency. Under future Scenario I it is likely that all three populations would persist on the landscape through the 21st century with some loss of resiliency to all three due to altered fire regimes and potential shifts in the population structure toward taller, older adults with fewer opportunities for plant recruitment. Synergies among the stressors evaluated could exacerbate potential future effects on the three populations. We anticipate Scenario II would result in a greater reduction in population resiliency for all three populations due to an increase in area that will be vulnerable to an altered fire regime, habitat loss from military expansion, and increasing temperatures. However, large amounts of habitat supporting resource needs will remain and will likely support high numbers of individual Joshua trees across the range.

Redundancy

We consider the current species redundancy to be high since there is a large amount of area currently supporting individual plants and the number of individuals across the range could be in the millions. Adverse impacts from threats are spread across a 6.4 million-acre area so it is not likely that catastrophic events, such as wildfire, would lead to the death of all individuals in the population. However, increasing temperatures or could affect large areas of the current mapped distribution in the future resulting in a decline in the distribution and loss of connectivity, which may lead to a decline in species redundancy. Future species redundancy could decline from current levels in areas with increasing minimum temperatures as a result of reduced seedling establishment and survival, so areas in YUJA East that are currently warmer than the other two populations may experience lower recruitment and ultimately a southern range contraction, similar to what was experienced over the course of about 8,000 years during the Holocene warming period. But areas of refugia are likely to support smaller populations in these southernmost areas. *Yucca jaegeriana* may have the ability to colonize areas north of its current distribution, which could offset a southern range contraction. If this occurs, redundancy could remain high (assuming their pollinators also persist), since populations would continue to include high numbers of individuals distributed across a large land area. Regardless of whether a northern expansion occurs, we anticipate the species will continue to have very high numbers of individuals distributed across regional landscape-scale areas through the 21st century since about 3.2 million ac (1.3 million ha) of the mapped distribution is under management/conservation designations that support more intact ecosystems.

Representation

Current species representation is likely high as individuals occupy relatively diverse areas within the Mojave, Great Basin, and Sonoran Deserts. The three populations encompass a wide range of elevation and climate gradients, with cooler temperatures in the northern populations and higher summer rainfall in the eastern populations. This large gradient also results in a variety of vegetation associations in areas where *Yucca jaegeriana* occurs. While ecoregion diversity does not decline under future Habitat Loss scenarios, altered fire regimes and increasing temperatures could affect large areas of the current mapped distribution in the future causing a decline in connectivity and ecological diversity, leading to a future decline in species representation. However, because of the large range-wide distribution and landscape diversity we anticipate there will be areas of refugia throughout the range where the species will persist. The species may also have the ability to colonize areas north of its current distribution or higher elevations with cooler winter temperatures within its current distribution. Additionally, because about 3.2 million ac (1.3 million ha) of the mapped distribution will remain under management/conservation designations that support more intact ecosystems, we anticipate the species will continue to have high numbers of individuals distributed across an ecologically diverse landscape in the Mojave, Great Basin, and Sonoran Deserts through the 21st century.

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APPENDIX A

Joshua Tree Mapped Distribution, Metadata

Creating the Joshua Tree current mapped distribution used in the 2018 Species Status Assessment was an iterative process based on the distribution map published in Rowlands 1978. Rowlands' 1978 map was georectified and his mapped populations were heads-up digitized into the initial dataset. Several other mapping data were used to confirm or refine Rowlands' 1978 populations to create the final distribution model. They include:

Table 1A: Mapped Distribution Metadata

Layer Name	Source	Metadata Status
AApoints_distribution	Center for Conservation Biology, UC - Riverside,National Park Service, Joshua Tree National Park	metadata
InaturalistObs_FrakesQC_20170531	Inaturalist	no metadata
Frakes_YUBRdistribution Updates_May2017	N. Frakes/Joshua Tree National Park	no metadata
HexieMtns_YUBR_Distribution	N. Frakes/Joshua Tree National Park	no metadata
NorthEntrance_Distribution	N. Frakes/Joshua Tree National Park	no metadata
WhiteTank_Distribution	N. Frakes/Joshua Tree National Park	no metadata
UT_YuccaBrevifolia_JKellam_July2017_Distribution	J. Kellam/Bureau of Land Management	no metadata
CA_Herbaria_UTM	USFWS/Carlsbad Fish and Wildlife Service	no metadata
Jepson_KenOther	Jepson Herbarium	no metadata
Cole2003_UTM	K. Cole/USGS Southwest Biological Service Center	metadata
Cole2011KEI_UTM	K. Cole/USGS Southwest Biological Service Center	no metadata
Cole2011F2_UTM K. Cole/USGS	Southwest Biological Service Center	no metadata
GCPNMJTreeFire_UTM	Grand Canyon-Parashant National Monument	no metadata
GCPNMJTreeKnown_UTM	Grand Canyon-Parashant National Monument	no metadata
Godsoe_UTM	Godsoe *et al.*, 2009	no metadata
JOTR_pts_M1	?	no metadata
SEINet_occs_UTM	SEINet	no metadata
Mojave_Yubr_P	California Department of Fish and Wildlife	metadata
JoshuaTreesFortIrwin	Holton/Fort Irwin	no metadata
1992_Photogrammetry_Survey	Edwards Air Force Base	no metadata
2008_Lidar_Survey	Edwards Air Force Base	no metadata
2015_Lidar_Survey	Edwards Air Force Base	no metadata

APPENDIX B

Future Housing Density Model, Metadata

We used the Integrated Climate and Land-Use Scenarios (ICLUS) modelling tool developed by the U.S. Environmental Protection Agency (EPA) to predict future housing density growth in the Joshua Tree region of the Southwest (EPA 2009). The tool consists of a demographic and a spatial allocation model. Output from the demographic model is used in the spatial allocation model to "map" future housing density. Future housing density is based on county level population projections and projected in semi-decadal time steps through the end of the century. The primary assumption is that future growth is similar to growth patterns from the previous time step. In incorporating the A2 and B1 climate scenarios into county-level projections for the United States, the ICLUS tool attempted to be consistent with global scenarios. Fertility, mortality, and migration variables influenced the final outcome. Because this is a housing density model, only residential housing density is estimated in the final product.

We used housing density from 2005 as the initial time stem for each Scenario as the baseline to calculate the loss of potential Joshua tree habitat due to projected housing density growth. The difference between cell values from the 2095 projection for each Scenario was used to identify areas that were impacted by increased housing density. We used all default settings in the tool to project housing density in the B1 climate scenario and the A2 climate scenario out to 2095.

APPENDIX C

Representative Concentration Pathways (RCP), 2.6 and 8.5, Projected Climate Maps

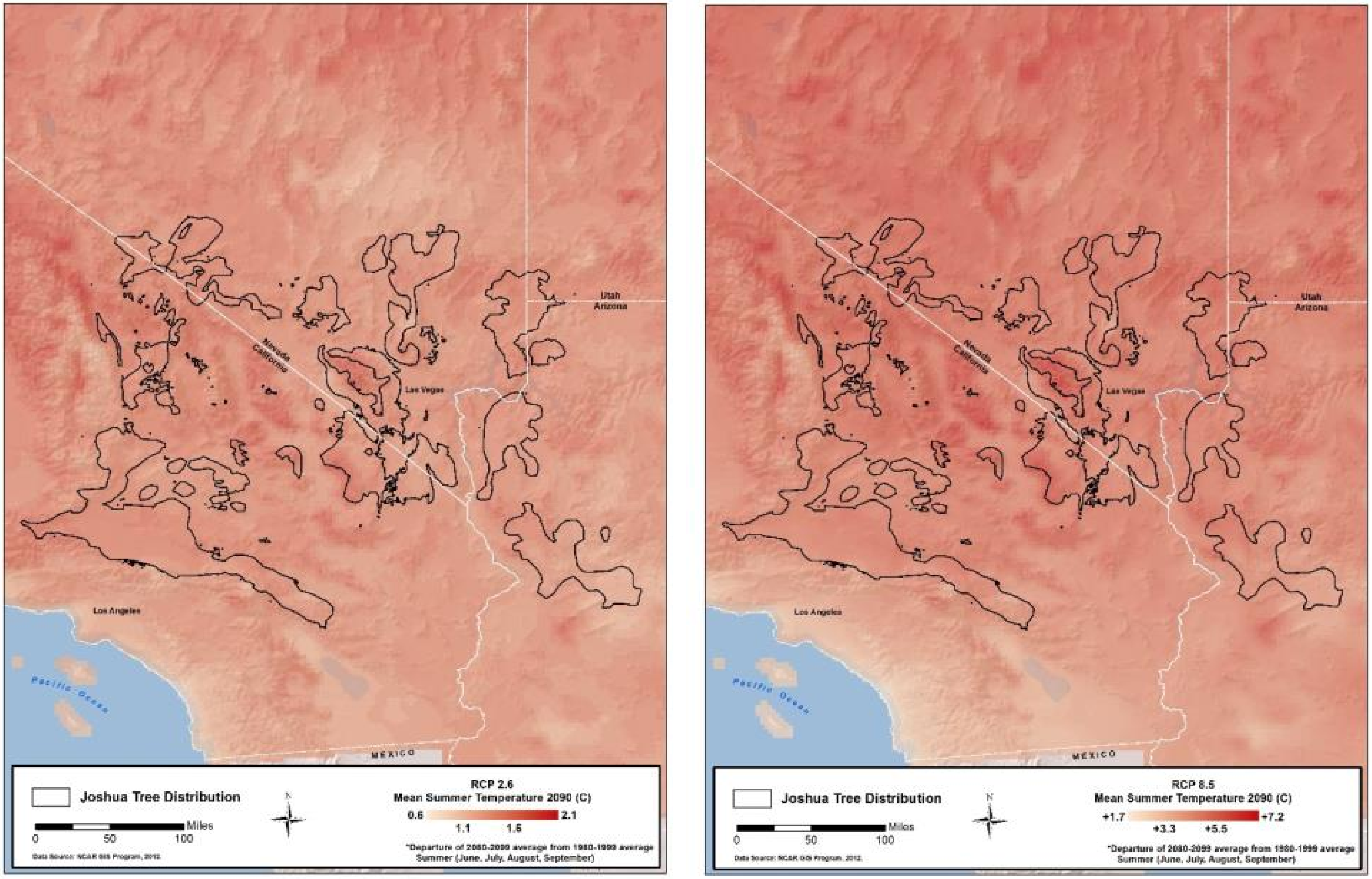

Figure 1C: Projected Departure of Average Summer Temperature in 2090, RCP 2.6 (Left) and 8.5 (Right)

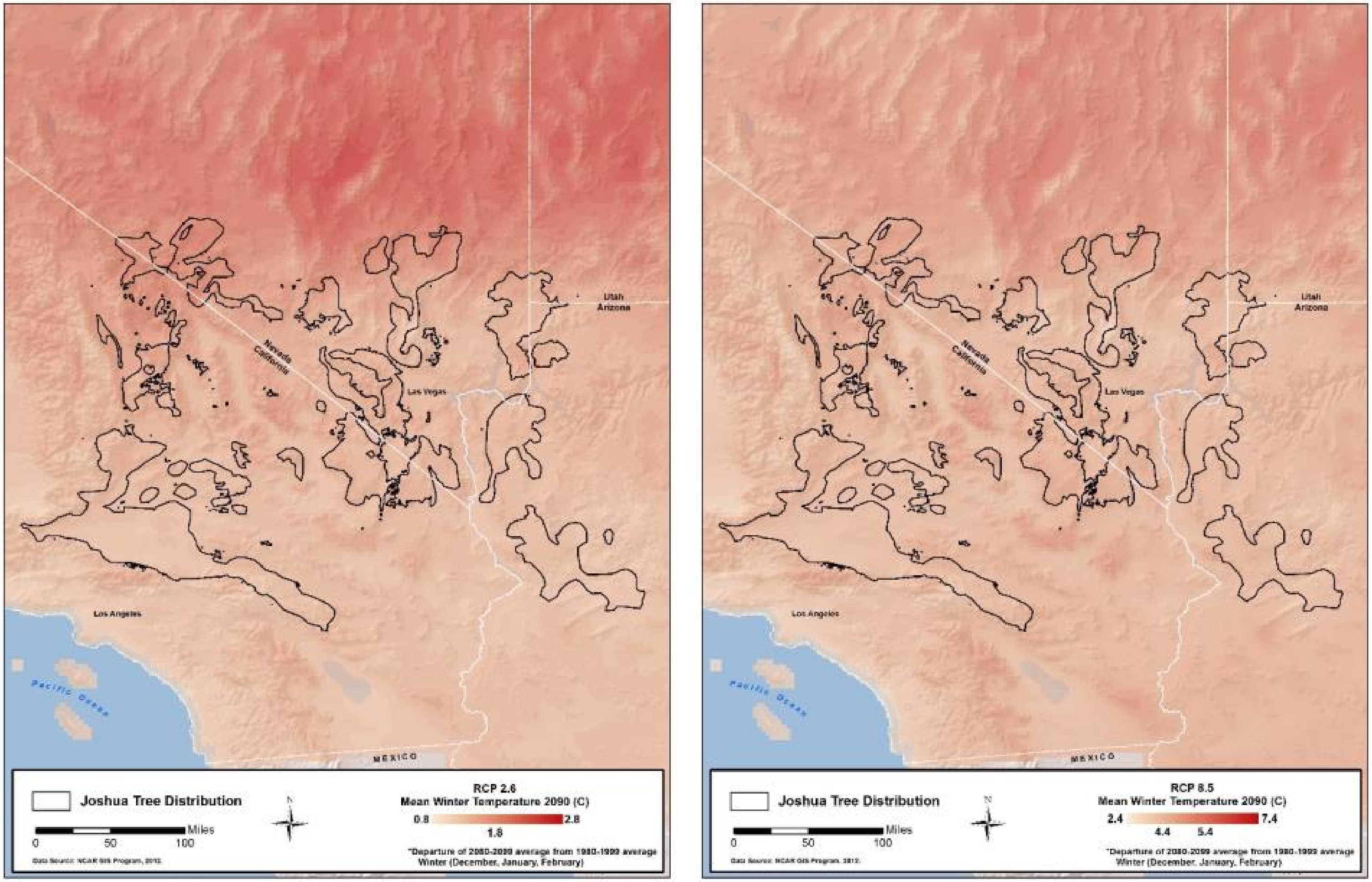

Figure 2C: Projected Departure of Average Winter Temperature in 2090, RCP 2.6 (Left) and 8.5 (Right)

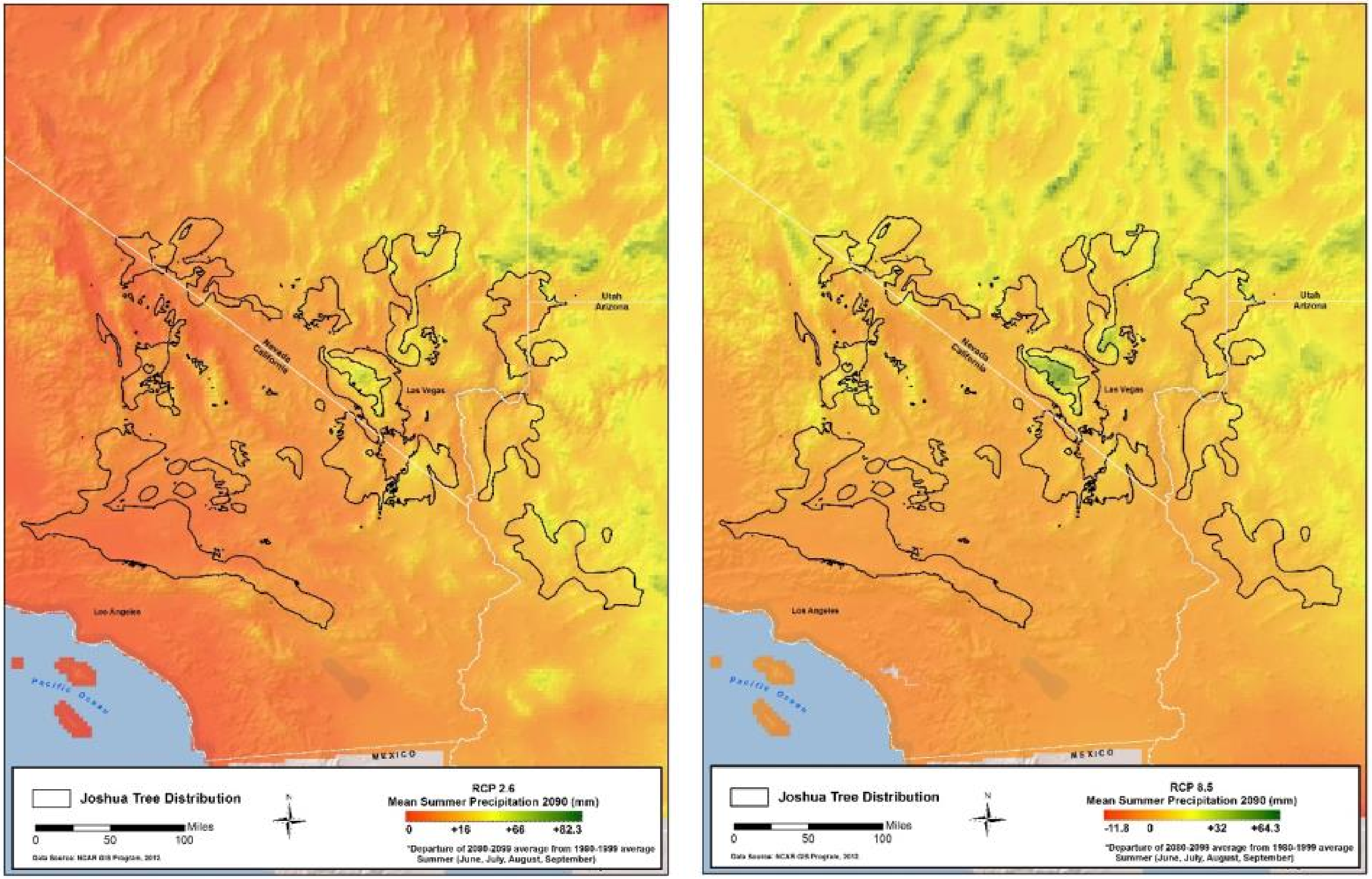

Figure 3C: Projected Departure of Average Summer Precipitation in 2090, RCP 2.6 (Left) and 8.5 (Right)

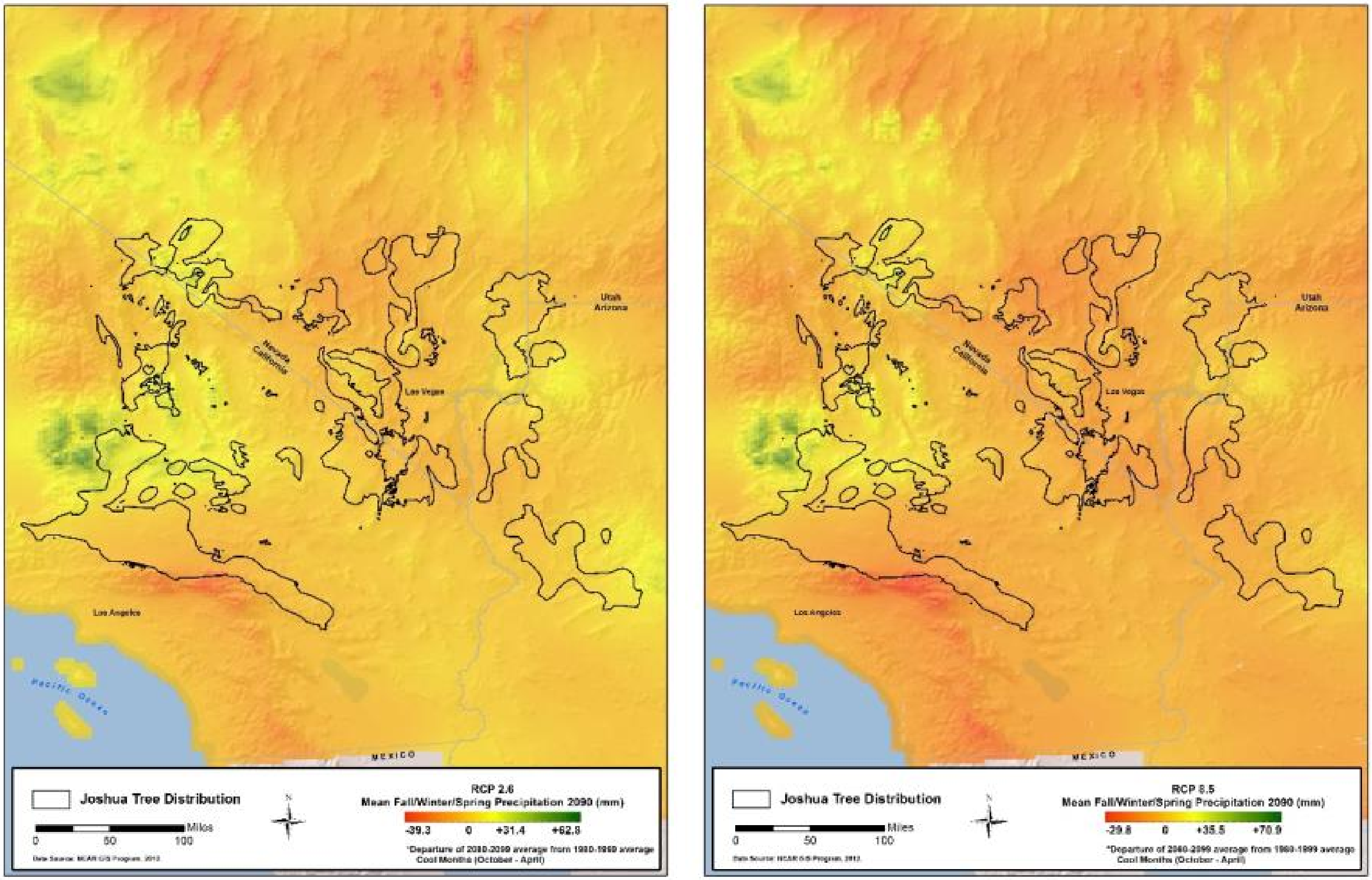

Figure 4C: Projected Departure of Average Cool Season Precipitation in 2090, RCP 2.6 (Left) and 8.5 (Right)