SPECIES STATUS ASSESSMENT REPORT

FOR

JOSHUA TREES

(*Yucca brevifolia* and *Yucca jaegeriana*)

Photo: Joshua trees (*Photo credit: Joanna Gilkeson*)

U.S. Fish and Wildlife Service
Carlsbad Fish and Wildlife Office
Carlsbad California

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EXECUTIVE SUMMARY

We, the U.S. Fish and Wildlife Service (Service), are revising this Species Status Assessment (SSA) report in response to a court ordered remand of the August 2019 "not warranted" 12-month findings for the two species of Joshua tree (*Yucca brevifolia and Y. jaegeriana*). The Court ordered us to reconsider whether the two species of Joshua tree should be listed under the Endangered Species Act of 1973 (Act), as amended (16 U.S.C. 1531 *et seq.*). This SSA Report is intended to provide the biological support for determining whether each species meets the definition of either a threatened or an endangered species, and if so, provide the biological and ecological information to inform any critical habitat designation. The SSA Report does not represent a decision by us whether or not to list the species under the Act. Instead, this SSA Report provides a review of the best scientific and commercial information available on *Y. brevifolia* and *Y. jaegeriana*.

Joshua trees occur in desert regions of the southwestern U.S. and are located on alluvial fans, plains, and bajadas throughout the Mojave, Great Basin, and Sonoran Deserts. They can be found throughout a wide range of vegetation communities between approximately 1,279–8,775 feet (390 and 2,675 meters) elevation. Joshua trees are often the tallest plant on the landscape where they occur but are not typically dominant in terms of vegetation cover. They are slow growing desert plants. They do not have growth rings, so accurately determining their age is quite difficult. The height of a Joshua tree divided by an estimate of growth per year is used to estimate age. Adult Joshua trees may live to be 100 to several hundred years old, with a generation time of 50 to 70 years. Due to their slow growth rate, it can take 30 to 70 years before an individual tree matures and flowers (Esque 2022b, pers. comm.). Joshua trees reproduce both sexually through an obligate mutualism with the yucca moth, as well as asexually through vegetative growth (clones). Optimal reproduction and recruitment of Joshua trees requires a convergence of events, including fertilization by its obligate pollinators, seed dispersal and caching by rodents, seedling emergence from a short-lived seed bank triggered by isolated late-summer rainfall, exposure to cold temperatures that improve seedling and juvenile growth and survival, and survival through the highly vulnerable early life stages.

Joshua trees require that habitat and demographic needs be met for populations to be resilient. Joshua trees rely on habitat elements that include appropriate substrate, appropriate climatic conditions, yucca moth pollinators, rodent seed-caches, nurse plants, and mechanisms for dispersal. Appropriate climatic conditions include adequate amounts of annual precipitation {between 4.7 and 16.9 inches (in) [11.8 and 42.9 centimeters (cm)]}, summer monthly precipitation in excess of 1.1 in (2.9 cm) in the months of July and August, average summer temperatures based on the range experienced historically [67 to 91° Fahrenheit (F); 19.4 to 32.8° Celsius (C)], and winter temperatures between 29 and 50° F (-1.7 and 10° C). To reproduce successfully, Joshua trees need yucca moth pollinators, nurse plants, and seed-caching rodents. To evaluate the biological status of *Yucca brevifolia and Y. jaegeriana* both currently and into the future, we assessed a range of conditions to allow us to consider the species' resiliency, redundancy, and representation. We evaluated how anthropogenic threats such as habitat loss, invasive plant species, increased risk of wildfire, climate change, and predation influence the resiliency, redundancy, and representation of Joshua trees in regional analysis units to describe the species' future viability.

The viability of *Yucca brevifolia* and *Y. jaegeriana* depends on maintaining multiple redundant and resilient populations over time across each species' distribution. Both species are adapted to arid desert habitats with periods of drought and variable precipitation. Under climate change projections, we anticipate alteration of precipitation and temperature patterns as models forecast warmer temperatures and more variability in precipitation, including the potential for extreme precipitation events and prolonged drought. Given the inherent uncertainty in forecasting the future effects of climate change, we utilized the results of eight bioclimatic models to project the species' future status, including the potential for habitat degradation (reduced tree densities and recruitment); loss of occupied habitat; range contractions; and the maintenance of climatically favorable habitat in climate refugia [areas of habitat projected to be climatically favorable where all the species needs (e.g., sufficient pollinators, survival, and appropriate recruitment conditions to maintain population abundance) are forecasted to be met]. We also utilized recently developed models to evaluate future habitat loss and the increased risk of wildfire within the context of the future climate scenarios and project future conditions for invasive grasses and predation. We project resiliency, redundancy, and representation of *Y. brevifolia and Y. jaegeriana* under two future scenarios with a timeframe of 80 years, until the end of the century (2070 to 2099). We did not develop a new model specifically for Joshua tree and instead relied on existing models that varied depending on the parameter evaluated (e.g., land use, invasive grass cover, and climate variables). All data considered were based on Representative Concentration Pathway (RCP) greenhouse gas concentration scenarios adopted by the Intergovernmental Panel on Climate Change (IPCC) with the exception of invasive grass cover. Both RCP 4.5 and RCP 8.5 were selected because they provide a plausible range of future conditions considering the potential for both near-term mitigation (RCP 4.5) and continued increases in greenhouse gas emissions (RCP 8.5). The two future scenarios provide a spectrum of the best available information regarding potential habitat loss and degradation, existing regulatory mechanisms, and beneficial conservation measures expected to occur during this period. These scenarios are:

1. **Scenario I** – a continuation of current threats under the RCP 4.5 climate scenario and a projected 2 to 3° C temperature increase.

2. **Scenario II** – an increase in the magnitude of current threats under the RCP 8.5 climate scenario and a projected 5° C temperature increase.

Under both scenarios, increased temperatures and prolonged drought are the highest magnitude threats, resulting in the potential loss of occupied habitat, range contractions, and habitat degradation across 60 to 99 percent of the current distribution, depending on the scenario, with the greatest impacts at lower elevations and latitudes. We forecast that Joshua trees will persist in degraded and marginal habitat, but at lower tree densities than current conditions, and in climate refugia at higher elevations and latitudes where species needs are projected to be met. Projected climate refugia correspond with middle and high elevation vegetation communities that are also estimated to have increased risk of high severity wildfires, with the potential for higher probability of natural ignition sources, and higher frequency of wildfire in the northeast. We project that wildfires will result in tree mortality, decreased tree densities, and that recruitment may be limited as the habitat recovers, which could take 80 to 100 years or more depending on drought conditions. Areas at lower elevation, particularly to the northeast, are forecasted to have higher frequency wildfires in areas expected to be substantially degraded by climate change. We forecast substantial reductions in tree density and that recruitment may be limited due to the impacts of climate change. Frequent fires increase mortality of younger age-classes and nurse plants, and contribute to increases in invasive grass cover. Approximately 12 to 18 percent of the remaining occupied habitat is forecasted to be impacted by wildfire by the end of the century; this range assumes a 50 to 100 percent increase in the proportion of Joshua trees' habitat that has burned in the last 60 years (8 percent). We forecast that habitat may recover following single, low to moderate severity, low frequency wildfires, though recovery may be hampered by increased drought. Joshua tree habitat is unlikely to recover from multiple wildfires or a single high severity wildfire before the end of the century. Invasive grass species occur across the distribution of *Yucca brevifolia* and *Y. jaegeriana* and have the potential to alter soil moisture and wildfire regimes. High invasive grass cover is limited and occurs primarily in the northeast in areas that have burned frequently. Minor projected increases in habitat loss from urbanization and renewable energy development are projected to overlap areas of potential habitat loss at lower elevations due to the effects of climate change and are not forecasted to result in substantial additional increases in habitat loss or impacts to climate refugia. Herbivory and predation are currently low magnitude threats, exacerbated by the current extended drought conditions, and are resulting in damage and loss of individuals throughout the range of Joshua trees, though it is unclear how the magnitude of the threat compares to historical conditions. The highest magnitude of drought and drought-exacerbated predation and herbivory impacts has been documented in the southern portion of *Y. brevifolia* and are projected to increase under future climate change scenarios.

This SSA analyzes resiliency within six analysis units including two populations of *Yucca brevifolia* (YUBR North and YUBR South), three populations of *Y. jaegeriana* (YUJA North, YUJA East, and YUJA Central), and a Hybrid Zone (described further in **4.5 Regions Defined for Further Analysis**). We anticipate that all of the six analysis units will continue to be occupied at some level under both future scenarios. Under Scenario I at the end of the century (2070-2099), our analysis shows that resiliency will be reduced across all analysis units relative to current levels, except for the Hybrid Zone. *Yucca brevifolia* and *Y. jaegeriana* are projected to continue to occupy a large portion of their current distribution at higher elevation and northern latitudes in excess of 2.2-million acres [ac; 880,000 hectares (ha)] and 2.9-million ac (1.2-million ha) respectively, though lower elevations are projected to have lower tree density and limited recruitment. *Yucca brevifolia* analysis units are projected to maintain moderate to high resiliency and *Y. jaegeriana* analysis units are projected to have reduced resiliency that ranges from low to moderate. Due to the loss of occupied habitat and potential range contractions at lower elevations and latitudes, we forecast decreases in both redundancy and representation with the potential to lose genotypes adapted to more arid conditions along the southern limit of both species. However, both species are likely to withstand catastrophic events in the future though with reduced representation.

Under Scenario II, we anticipate increased reductions in the amount of climatically favorable habitat, but both species will continue to occupy relatively large and diverse area, though their distributions are shifted northward and are reduced compared to current conditions and Scenario I. *Yucca brevifolia* is projected to occupy 1.7-million acre (708,000 ha) and *Y. jaegeriana* is projected to occupy 2.3-million acre (913,200 ha) at the end of the century (2070-2099). We forecast substantial reductions in resiliency that may limit both species' ability to withstand stochastic events and only the northern most *Y. brevifolia* analysis unit is forecasted to have moderate resiliency at the end of the century. Substantial reductions in redundancy and representation may put both species at an increased risk for catastrophic events and limit the ability of the species to adapt to changes in environmental conditions. We forecast reductions in genetic variability including the loss of important adaptive genetic variation along the southern distribution and populations at northerly latitudes may not as well adapted to warming temperatures.

We acknowledge uncertainty in our future projections due to current information gaps, the inherent uncertainty in future climate projections, the potential for climate refugia and microclimates that are often not identified in coarse scale climate modeling, and the difficulty forecasting potential demographic changes and the species response for such a long-lived species that have maintained occupancy for thousands of years across a range of habitats. We lack range-wide demographic data and an understanding of the amount and frequency of recruitment required to maintain population abundance given the species' long lifespan. We also lack information on the population dynamics and environmental thresholds for the yucca moth species. For purposes of this SSA, we presume that yucca moth populations will track Joshua tree flowering and will experience similar losses of occupied habitat, potential range contractions, habitat degradation, and will occur in climate refugia projected for Joshua trees, though there is a high degree of uncertainty regarding these assumptions.

CHAPTER 1. INTRODUCTION

This report summarizes the results of an assessment conducted for the two species of Joshua tree (*Yucca brevifolia* and *Y. jaegeriana)*. We used an integrated and conservation-focused analytical approach, the Species Status Assessment (SSA), to assess the species' biological status for the purpose of informing our decision under the Act, as amended. The SSA Report, the product of conducting a SSA, is a concise review of the species' biology and other factors (both negative and positive) influencing the species, an evaluation of its biological status, and an analysis of the species' potential status under a spectrum of plausible future scenarios. As envisioned by our guidance document, the SSA Framework (Service 2016b, entire), a SSA Report begins with a compilation of the best available information on the species (taxonomy, life history, and habitat) and its ecological needs based on how we understand environmental factors act on the species and its habitat. Next, a SSA Report describes the current condition of the species' habitat and demographics, and the probable explanations for past and ongoing changes in abundance and distribution within the species' ecological settings (that is, areas representative of geographic, genetic, or life history variation across the range of the species). Lastly, the SSA forecasts the species' response to probable future scenarios of environmental conditions and conservation efforts (Rowland *et al*. 2014, entire). Overall, the SSA uses the conservation biology principles of resiliency, redundancy, and representation, collectively known as the "3Rs" (Shaffer and Stein 2000, pp. 308–311), as a lens through which we can evaluate the current and future condition of the species (Smith *et al*. 2018, entire). Ultimately, a SSA Report characterizes a species' ability to sustain populations in the wild over time based on the best scientific understanding of current and future abundance and distribution within the species' ecological settings. The SSA Report is intended to support all functions of the Endangered Species Program—including development of listing rules, recovery plans, and 5-year reviews—should the species warrant listing as an endangered or threatened species under the Act. The SSA Report is a living document, and we may update it periodically as new information becomes available.

The SSA Report for Joshua trees is intended to provide the biological information for determining whether each species meets the definition of either a threatened or an endangered species and if so, provide the biological and ecological information to inform any critical habitat designation. A SSA Report is, in essence, a summary of the available information about a species and, simultaneously, a biological risk assessment to aid decision makers who must use the best available scientific information to make policy-guided decisions. The SSA Report provides decision makers with a scientifically rigorous characterization of the species' biological and conservation status, focusing on the likelihood of whether the species will sustain populations within its ecological settings while also explicitly acknowledging uncertainties in that characterization. The SSA process and this SSA Report do not represent a decision by the U.S. Fish and Wildlife Service (Service) whether or not to list the species under the Act. Instead, a SSA Report provides a review of the best available scientific information for comparison to policy standards to guide decisions under the Act.

1.1 Species Overview

Joshua trees occur in the desert regions of the southwestern U.S. on alluvial fans, plains, and bajadas in parts of the Mojave, Great Basin, and Sonoran Deserts. It is often the tallest plant on the landscape where it occurs, growing up to 39 feet [ft; 12 meters (m)] tall depending on the species, but is not typically dominant in terms of vegetation cover (Esque 2022a, pers. comm.). It can be found throughout a wide range of vegetation communities between approximately 1,279–8,775 ft (390–2,675 m) elevation. Joshua trees are part of an obligate mutualism, and each species is pollinated by a specific species of yucca moth, which is solely responsible for pollination outside of a narrow zone of hybridization.

Joshua trees have generally been addressed in the literature as a single species; however, more recent references have identified at least two varieties or subspecies (*Yucca brevifolia* var. *brevifolia* and *Y. b*. var. *jaegeriana*). We consider the two entities to be two distinct species—the western Joshua tree (*Yucca brevifolia*) and eastern Joshua tree (*Y. jaegeriana*)—based on expert feedback (see **section 3.2 Taxonomy** below; Table 1-1) and we will treat them as two separate, listable entities. For the purposes of this analysis, we discuss both species together using the common name—Joshua tree(s)—when the discussion of information pertains to both species. Literature or conclusions specific to a single species are indicated by the species scientific name, where applicable.

Table 1-1. Taxonomical classification of Joshua tree.

Plantae	Tracheophyta	Magnoliopsida	Asparagales	Asparagaceae	*Yucca*	*brevifolia*
Plantae	Tracheophyta	Magnoliopsida	Asparagales	Asparagaceae	*Yucca*	*jaegeriana*

1.2 Previous Federal Actions (Petition History for Unlisted Species)

On September 29, 2015, we received a petition from Taylor Jones (representing Wild Earth Guardians), requesting that *Yucca 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 Act. On September 14, 2016, we published a 90-day finding in the Federal Register (Service 2016a), concluding that the petition presented substantial information indicating that listing the Joshua tree may be warranted. On August 15, 2019, we published 12-month findings (Service 2019) concluding that listing either *Y. brevifolia* or *Y. jaegeriana* was not warranted. On November 4, 2019, Wild Earth Guardians filed a complaint in the Central District of California challenging the analyses and listing decisions. The Court vacated and remanded the listing decisions back to the Service [*WildEarth Guardians* v. *Haaland*, 2021 WL 4263831 (C.D. Cal. Sept. 20, 2021)], ordering us to reconsider whether the two species of Joshua tree should be listed under the Act. The Court subsequently entered an order setting a response date of January 31, 2023. As a result, the Service is reconsidering its August 2019 12-month findings and has revised the SSA Report (this document).

1.3 State Listing Status

Joshua trees are not listed under any state endangered species act. California recently evaluated a petition to list the western Joshua tree (*Yucca brevifolia*) and their status assessment indicated that listing was not warranted. The Fish and Game Commission met in June 2022 and a final listing decision is not anticipated until October 2022.

CHAPTER 2. METHODOLOGY AND DATA SOURCE

This document draws scientific information from resources such as peer-reviewed literature, reports submitted to the Service and other public agencies, occurrence information in Geographic Information Systems (GIS) databases, and expert experience and observations. It is preceded by, and draws upon, analyses presented in the 90-day finding (Service 2016a, entire), the 2018 Joshua tree SSA Report (Service 2018, entire), and 12-month finding (Service 2019, entire). Finally, we coordinated with our Federal, State, Tribal, and local partners, including researchers and experts involved in field investigations. We consider the information we obtained to be the most current scientific conservation status information available for Joshua trees. In the future, should additional information become available, and the need arise, we will revise this document to reflect the most current scientific and conservation status information available.

2.1 Species Status Assessment Framework

The Service uses the SSA analytical framework (Figure 2-1; Service 2016b, entire) designed to assess 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 under the Act, eliminates duplicative and costly processes, and allows the Service to strategically focus on our core mission of preventing extinction and achieving recovery. 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 a range of the potential conditions that the species or its habitat may face and discusses a range of plausible future scenarios if those conditions come to fruition. The range of plausible future scenarios include consideration of the threats most likely to impact the species in the future, at the individual, population, or range-wide scales in the future.

For this assessment, we define species viability as the ability of the species to sustain populations in the natural ecosystem over time. Joshua trees can live several hundred years and have a generation time of 50 to 70 years (Esque *et al*. 2015, p. 89). There is increasing uncertainty as persistence is modeled into the future; therefore, we will use timeframes for future model forecasts that are available for threats identified in this assessment and will project species viability at the end of the century (2070-2099). We developed our future condition evaluation based on these threats, while acknowledging there is uncertainty on how these threats may change singly and cumulatively, and their effect on each species.

Using the SSA framework (Figure 2-1), 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, and the species viability using the principles of resilience, redundancy, and representation. 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.

1. **Resiliency** is the ability of a species to withstand stochastic events and normal year-to-year variations in both environmental conditions (i.e., temperature; rainfall; and periodic disturbances such a drought, wildfires, or floods) and demographic conditions [i.e., mortality, fecundity; (Redford *et al*. 2011, p. 40)]. Determined by the size and growth rate of the species population(s), resiliency can be evaluated to gauge the ability of a species to withstand the natural range of favorable and unfavorable conditions.

   In many instances, however, data are insufficient or completely lacking regarding a population's size and growth rate. In the absence of such data, it can be reasonable to examine other characteristics that may serve as surrogate indicators of general population health and subsequently, resiliency. Essentially, an assessment of the availability of a species' identified needs (e.g., suitable habitat, resources) may allow us to make assumptions about the potential resiliency of any given population. However, unless there is a documented positive correlation between species needs availability and a population's known demographic condition, the uncertainty regarding such assumptions must be made clear.

2. **Redundancy** is the ability of a species to withstand catastrophic events that would result in the loss of a substantial component of the species' total overall population. Such a loss could be of one or more populations of a species which is comprised of multiple populations or the catastrophic loss of a substantial number of individuals from a species with only a single population. However, redundancy is not simply a measure of the total number of individuals or populations of a species, but instead must also be evaluated in the context of an assessment of reasonably plausible catastrophic events. For example, a species with numerous small populations does not necessarily translate to a greater ability to withstand catastrophic events if those populations are very close together, and the only reasonably plausible potential catastrophe is one that would affect them all equally. Conversely, a species with only one population, but one which is very large and widely distributed, could have a high ability to withstand a catastrophic event that would only affect a small percentage of the total overall population. Therefore, our characterization of a species' redundancy takes into consideration both an assessment of the size and distribution of its population(s), and an evaluation of the kinds and likelihood of reasonably plausible catastrophic events to which the species could be exposed.

3. **Representation** is the ability of a species to withstand and adapt to long-term changes in environmental conditions (i.e., significant changes outside the range of normal year-to-year variations). The measure of a species' representation may be determined by the breadth of genetic diversity within and among populations, however, in the absence of information on a species' genetic diversity, we may also evaluate a species' known environmental diversity (i.e., the diversity of environmental conditions over which it is known to occur) as an alternative measure of its ability to withstand and adapt to long-term changes.

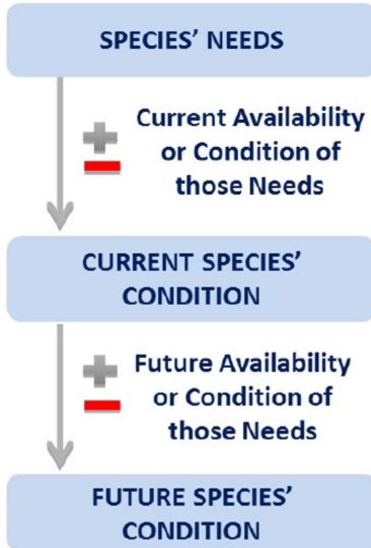

Figure 2-1. The step-wise process for assessing a species' status, as envisioned by the Services' SSA Framework (Service 2016b, pg. 6).

Using the SSA framework, we consider what the species needs to maintain viability by characterizing the status of Joshua trees in terms of its resiliency, redundancy, and representation. The species' biology, ecology, and habitat requirements are described in Chapter 3; the current distribution and abundance are described in Chapter 4, and the species' needs are described in Chapter 5. In Chapter 6, we discuss the factors influencing viability. Chapter 7 includes an assessment of Current Conditions based on the needs outlined in Chapters 3 and 4. Lastly, in Chapter 8 we forecast plausible future scenarios for Joshua trees based on the species' biology and current and future threats. As a matter of practicality, the full range of potential future scenarios and the range of potential future conditions for each potential scenario are too large to analyze and describe them individually. Therefore, the chosen scenarios do not include all possible futures, but rather include specific plausible scenarios that represent examples from the continuous spectrum of possible futures.

In summary, the SSA is a scientific review of the best information available, including scientific literature and discussions with experts, related to the biology and conservation status of the two species of Joshua trees.

2.2 Species Needs

The SSA Report includes a compilation of the best available biological information on Joshua trees including their ecological needs based on how environmental factors are understood to act on Joshua trees and their habitat.

1. Habitat Needs: These resource needs are those life history characteristics that influence the successful completion of each life stage.

2. Demographic Needs: These components of Joshua tree's life history profile describe the resources, circumstances, and demographics that most influence **resiliency** of the populations.

3. Species Needs: This is an exploration of what influences **redundancy** and **representation** for Joshua trees. This requires an examination of the Joshua trees' evolutionary history and historical distribution to understand how Joshua trees function across its range.

2.3 Current Condition

The SSA Report describes the current known condition of Joshua trees' habitat and demographics, and the probable explanations for past and ongoing changes in abundance and distribution across the current range of both species representing their geographic, genetic, and life history variation. We considered the distribution, abundance, and factors currently influencing the viability of Joshua trees. We identified known historical and current distribution and examined factors that negatively and positively influence Joshua trees. Scale, intensity, and duration of threats were considered for their impacts on the populations and habitat across life history stages.

The current condition analyses are described for each species including two analysis units of *Yucca brevifolia* (YUBR North and YUBR South), three analysis units of *Y. jaegeriana* (YUJA North, YUJA East, and YUJA Central), and a Hybrid Zone (Figure 2-2). We gathered information from researchers and stakeholders to describe current conditions. Joshua trees' current distribution is informed by a recent empirical study completed by U.S. Geological Survey (USGS; Esque 2022b, pers. comm.). Current conditions evaluated the status of the Joshua trees from approximately 2010 through 2022 depending on the available information. Additional detail on the current condition analysis methodology is presented in Chapter 5.

2.4 Future Condition

In the future conditions section of the SSA Report, we evaluate how the threats identified are likely to affect Joshua trees' needs into the future and forecast Joshua trees' response to a range of plausible future scenarios of environmental conditions and conservation efforts. This involves an analysis and description of a range of plausible future environmental conditions and the projected consequences on the species' ability to sustain populations in the wild over time as based on resiliency, redundancy, and representation. For this evaluation, the future extends only as far as we can reasonably project the future threats and the Joshua trees' responses to those threats; in addition, the uncertainty increases the further into the future we look. For example, there are several bioclimatic models available that project changes in the area that will be climatically favorable habitat for Joshua trees in the future. The bioclimatic models typically forecast to the end of the century but there is uncertainty in what magnitude and duration of increased temperatures and drought stress will survival and recruitment become impaired, particularly since Joshua trees' are long-lived species. To establish a reasonable timeframe, we consider the life-history characteristics, threat-projection timeframes, and environmental variability. Given Joshua trees' long generation time and the importance of the effects of climate change, we assess the potential response of Joshua trees under two future scenarios that illustrate a plausible range of environmental and conservation conditions at the end of the century (2070-2099).

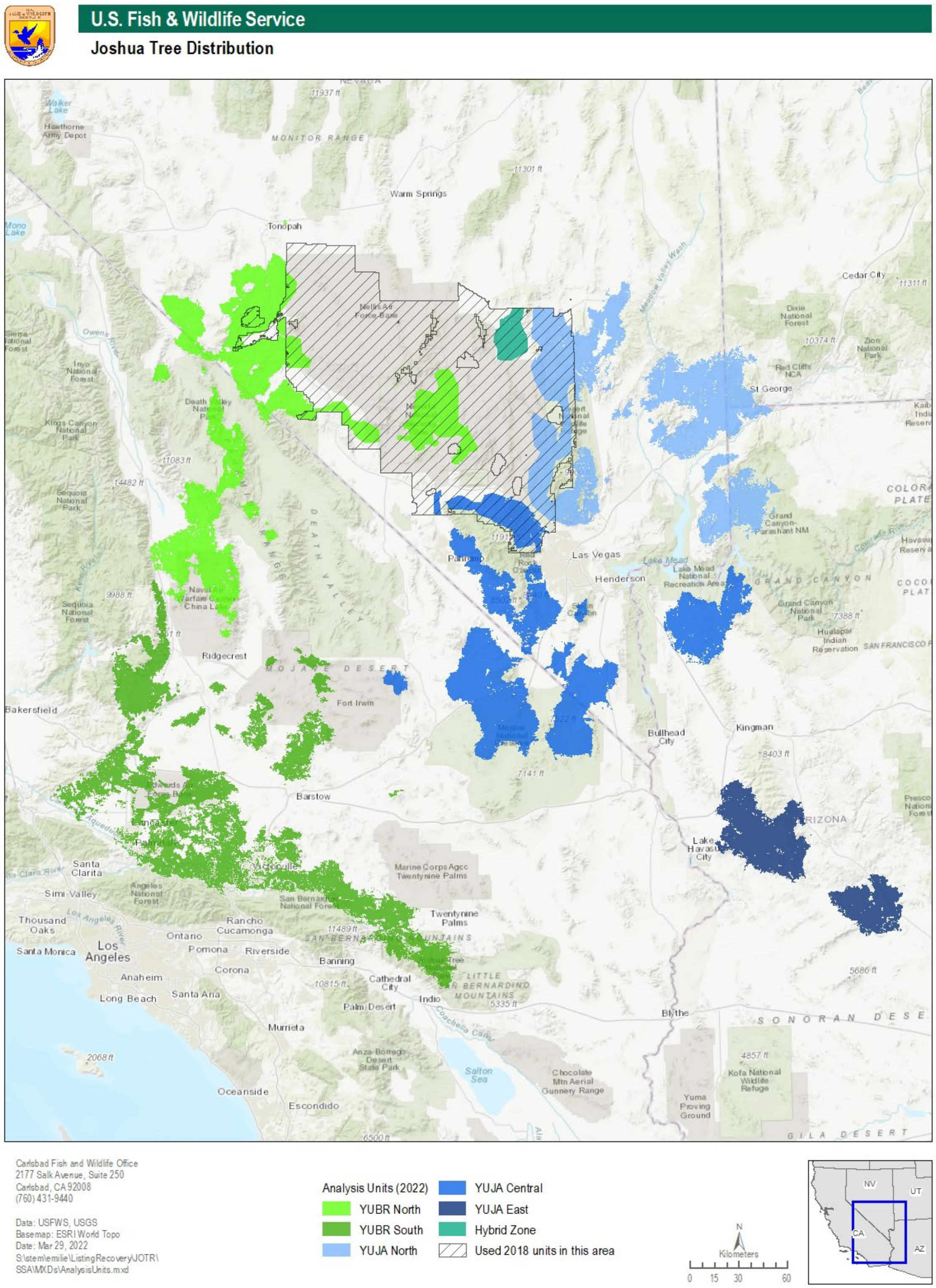

Figure 2-2. Joshua trees analysis units (Esque 2022b, pers. comm.).

CHAPTER 3. SPECIES BACKGROUND AND ECOLOGY

3.1 Physical Description

Joshua trees are 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 which have evolved with their obligate yucca moth pollinators. The size and growth form of Joshua trees also often vary with site and climatic conditions (Simpson 1975, p. 74; Rowlands 1978, p. 12). Hybrids occur in a smaller geographic area compared to the rest of the range, toward Joshua trees' northern limit and are not reliably identifiable from morphological characteristics alone (Smith 2022, pers. comm.).

Yucca brevifolia is 16–40 ft (5–12 m) tall, evergreen xerophytic monocot with a somewhat spongy, indehiscent (remaining closed at maturity) fruit. The leaves are between 7.5 and 14.6 inches [in; 19–37 centimeters (cm)]; long and are clustered in rosettes at the branch ends. Radial and vertical growth is simultaneous (Simpson 1975, p. 20) with branching occurring only following the first flowering (McKelvey 1938, p. 130). Following flowering, growth of the main stem in *Y. brevifolia* is replaced by axillary shoots that emerge from near the base of the inflorescence. Sympodial branching occurs after the death of each season's terminal bud and growth is continued by one or more lateral shoots (Simpson 1975, p. 32). The flowers are nearly spherical with short, wide petals that curve over the tip of the pistil and occur in dense, heavy panicles. The flowers are pollinated by *Tegeticula synthetica*, a species of yucca moth.

Yucca jaegeriana is a shorter [9–20 ft (3–6 m)] evergreen xerophytic monocot with spongy, indehiscent fruit. *Yucca jaegeriana* displays dichotomous branching, where the apical meristem divides into two independently functioning branches (Simpson 1975, p. 54) and has shorter leaves [less than 8.7 in (22 cm)] and shorter height to first branching at 2.3–3.3 ft (0.75–1.0 m) than *Y. brevifolia* resulting in a denser canopy (Figure 3-1; McKelvey 1938, p. 138). 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). 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 *Yucca brevifolia* and *Y. jaegeriana* is strongly correlated with the physical characteristics of its obligate moth due to coevolution (Figure 3-1; Godsoe *et al*. 2009, p. 820; Yoder *et al*. 2013, p. 11) with *Tegeticula antithetica* having a shorter ovipositor than the *Y. brevifolia* pollinator, *T. synthetica*.

Joshua trees have several anatomical features to conserve water. The leaves have a 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 (Simpson 1975, p. 197). Another adaptation to retain water is the plant's secondary tissues including the outer bark, periderm, which conducts water and holds a quantity of water several times the plant's weight (Simpson 1975, p. 72). Similar to other monocots (e.g., grasses), Joshua trees have a relatively shallow, fibrous root system that becomes more extensive in the first few weeks following germination (Simpson 1975, p. 12). An extensive root system is presumed to enable mature Joshua trees to survive long periods of drought, and roots are estimated to extend up to

36 ft (11 m) from the adult tree (Bowns 1973, p. 41). This data point came from a single individual and additional research is required to inform the rooting depth and distance.

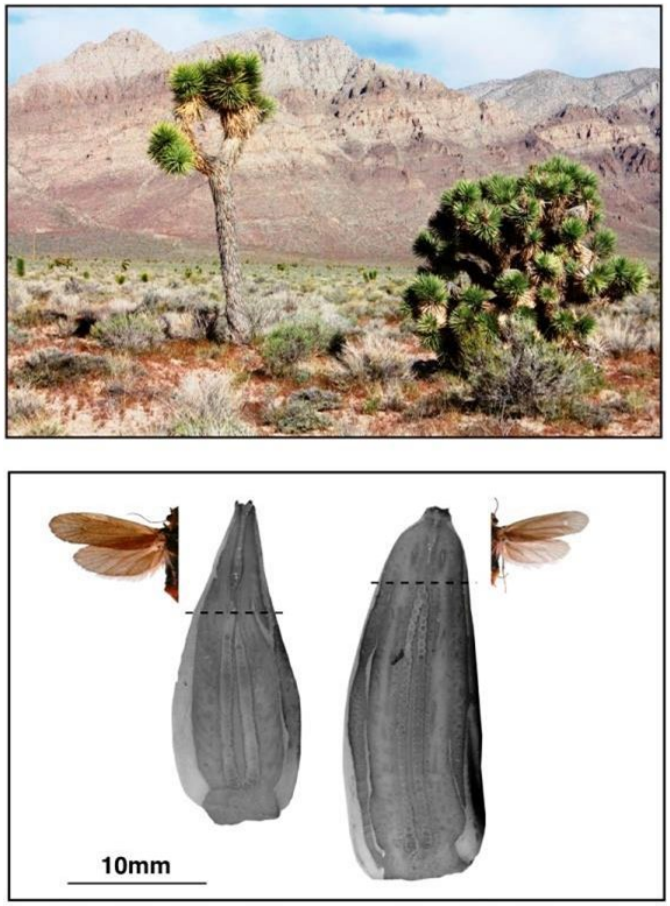

Figure 3-1. Top panel: *Yucca brevifolia* (left) and *Y. jaegeriana* (right) growing side by side in Tikaboo Valley, Nevada (Photo by Christopher I. Smith, used with permission). Bottom panel: Cross sections of pistils from *Y. brevifolia* (left) and *Y. jaegeriana* (right) showing differences in style 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).

3.2 Taxonomy

Yucca brevifolia 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 the *Y. brevifolia* classification 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* 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* was described by (Munz 1958, p. 88), based on the production of offshoots from underground rhizomes, but no taxonomic assessment has accepted *Y. brevifolia* var. *herbertii* as a taxonomic entity distinct from *Y. brevifolia* (Wallace 2017, p. 3)

Research suggests *Yucca brevifolia* var. *jaegeriana* is a distinct species. Lenz 2007 (Lenz 2007, p. 100) evaluated the morphological and pollinator differences and Royer *et al*. 2016 (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, *Y. brevifolia* diverged at least 5 million years ago possibly due to geographic separation by the Bouse Embayment (a Pliocene Era chain of lakes) (Smith *et al*. 2008a, p. 2682). 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*. 2013, p. 4; Royer *et al*. 2016, p. 136); the Hybrid Zone will be analyzed separately.

Based on these analyses (Lenz 2007, entire; Smith *et al*. 2008b, entire; Royer *et al*. 2016, entire), and correspondence between the Service and editors of the Jepson Manual (Wallace 2017, p. 2) we consider *Yucca brevifolia* var. *brevifolia* and *Y. b.* var. *jaegeriana* to be two distinct species, and we will treat them as two separate listable entities—*Y. brevifolia* and *Y. jaegeriana*—respectively. For this analysis, we discuss both species together using the common name—Joshua tree—when the discussion of information pertains to both species. Species specific references and conclusions are indicated with the appropriate scientific name.

3.3 Genetics

We currently lack information to characterize Joshua trees' genetic variability and population structure within each separate species. We expect that certain phenotypes or populations are adapted to the unique environmental conditions where they occur, given the large range and variety of habitats where Joshua trees occur. The range of Joshua trees are currently being modeled by USGS into provisional ecotypes based on a suite of environmental parameters, but the results were not available for this analysis and are expected in 2023 (Esque 2022a, pers. comm.). The same research team is currently implementing a genetic study to map the Joshua tree genome, assess genetic diversity, genetic variability for climate adaptation, and population structure across the known range of the Joshua trees (Smith 2022, pers. comm.); however, the results of that study were also not available for this analysis and are expected in 2023.

3.4 Life History

Joshua trees are a slow growing, desert plant. They do not have growth rings, so accurately determining their age is quite difficult. The height of a Joshua tree divided by an estimate of growth per year is used to estimate age. Adult Joshua trees may be up to several hundred years old but a more common lifespan is about 150 years. They can reproduce via several mechanisms, have unique habitat and ecological needs, and can disperse through environmental and biological means. The Joshua tree life cycle includes seedling, established individual, juvenile, and adult stages (Figure 3-2). The life history of both *Yucca brevifolia* and *Y. jaegeriana* relies on a complex set of interactions between individual plants, yucca moths, seed dispersers, herbivores/predators, and abiotic conditions for successful reproduction and survival to a reproductively mature adult (Figure 3-2). Joshua trees reproduce sexually through pollination and seed production as well as asexually through vegetative growth (clones). We lack information on the relative contribution of sexual and asexual reproduction and if the proportion varies regionally. 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 exposure to cold temperatures that improve seedling and juvenile growth and survival (Went 1957, p. 173).

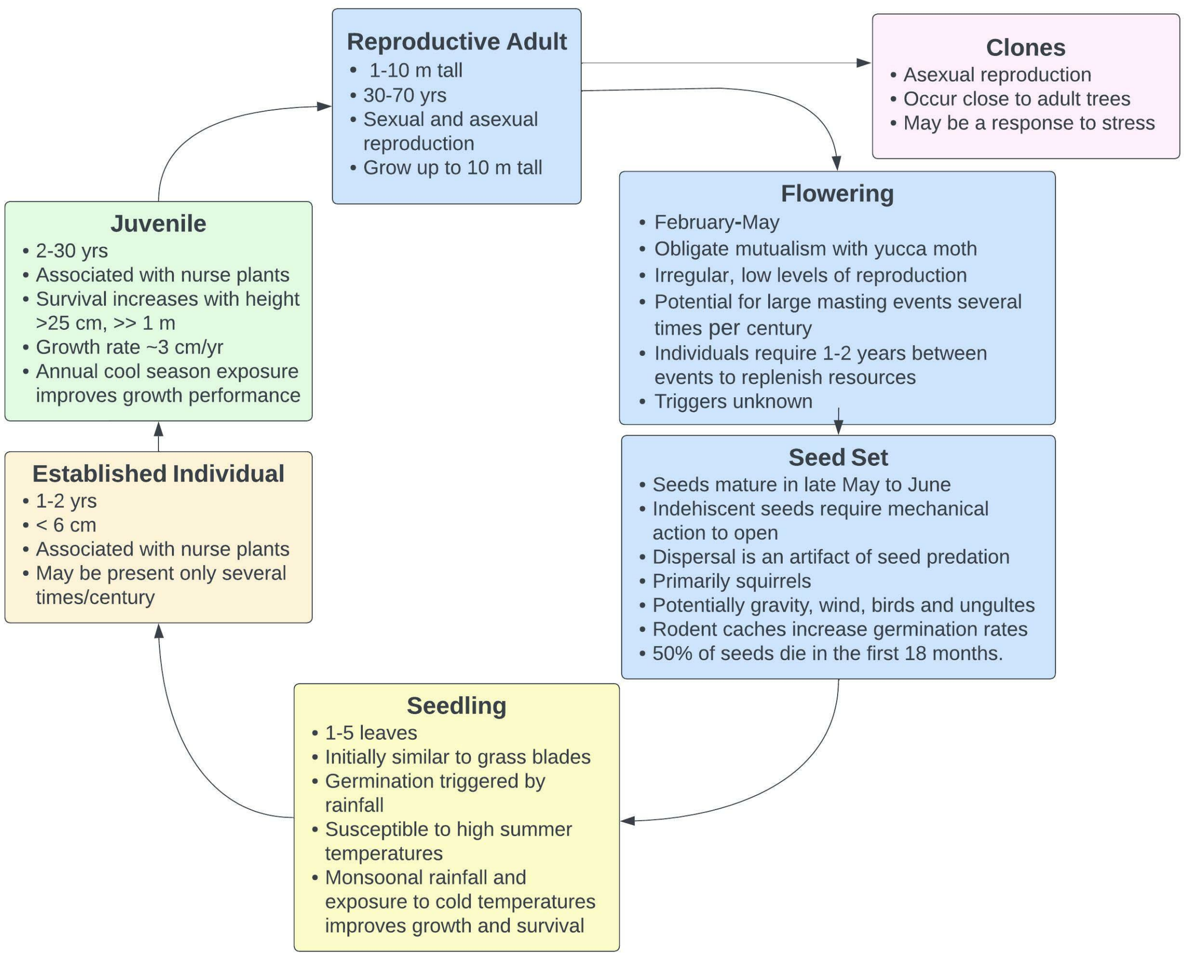

Figure 3-2. Joshua tree Lifecycle. Input and review provided by Todd Esque (Esque *et al.* 2015, entire; Esque 2022a, pers. comm.).

3.4.1 Asexual Reproduction

Joshua trees can also reproduce asexually by rhizomes, branch-sprouts and/or basal-sprouts (Figure 3-2; Gucker 2006, p. 8). Clonal resprouts can flower and produce seeds in as little as 2 years, including post-fire resprouts (Esque 2022a, pers. comm.). The clonal life strategy is an evolutionary adaptation to secure individual and population persistence during periods of demographic and environmental stochasticity. Clonal reproduction in Joshua trees has been proposed as a means for individuals to increase nutrient and water intake in marginal conditions (Harrower and Gilbert 2021, p. 11), as a response to stress (e.g., drought stress and wildfire; Esque 2022a, pers. comm.), in conditions where seedling establishment is difficult, as a response to a lack of pollinators, and when sexual reproduction fails (Rowlands 1978, p. 50; Harrower and Gilbert 2021, p. 11). Asexually reproduction is not a means of dispersal in Joshua trees because the vegetative growth does not detach and reestablish away from the adult tree as is observed in other plant species such as *Cylindropuntia* sp. (cholla) and *Arundo donax* (giant reed). Individual longevity through vegetative reproduction has also been hypothesized to compensate for low sexual recruitment commonly observed with clonal plant populations (de Witte and Stoecklin 2010, p. 866). Joshua trees' population resiliency is strongly tied to the persistence and genetic diversity of extant long-lived clones. Although long-lived clones maintain populations, they reflect genotypes successful under past conditions and may not have the capacity to adapt to rapidly changing environmental conditions and the lack of reproductive fitness may make them more susceptible to extirpation.

Most of the documented large, clonal populations occur in *Yucca brevifolia* in the southern portion of the species' range and at high elevation such as Walker Pass in the slopes of the Sierra Nevada (Simpson 1975, p. 73). These high elevation regions are characterized by cold temperatures, high winds, and abundant snowfall; therefore, rhizome production has also been proposed as an adaptation enabling migration into more severe climatic regions (Simpson 1975, p. 437). However, the clonal growth habitat was also determined to be the predominate reproductive strategy at low elevation sites along the southern limit of *Yucca brevifolia* in Joshua Tree National Park (JTNP) over a 2-year study. Sexual reproduction was considered minimal to absent in these areas, in part because climatic conditions did not support flowering or yucca moth populations (Harrower and Gilbert 2018, p. 6). Research studies have used a distance of 3.3 ft (1 m; Barrows and Murphy-Mariscal 2012, entire) to 6.6 ft (2 m; Sweet *et al*. 2019, entire) from an adult tree to distinguish seedlings from clones; and there is some indication that the distance of clones from adult trees may be species specific (Sweet 2022, pers. comm.). However, this limit has not been tested through a genetic study making it difficult to determine clones from juvenile trees. Earlier work in blackbrush vegetation community indicated that Joshua tree roots may extend up to 36 ft (11 m) from adult trees (Bowns 1973, p. 41), but additional research is required to inform the average rooting depth and distance of each species of Joshua tree.

3.4.2 Sexual Reproduction

Sexual reproduction requires flower production, pollination, seed production, seed dispersal, and germination. Joshua trees typically flower between February and May throughout their range (Figure 3-2; Gucker 2006, p. 9; Harrower and Gilbert 2018, p. 2). The percent of Joshua trees flowering and producing fruit is unknown and has been characterized as irregular (Esque *et al*. 2010, p. 11). Although large masting events do not happen very often, there is typically a small number of trees flowering in most years (Smith 2022, pers. comm.) There is geographic variability in masting events across the range of Joshua trees, though the pattern and frequency is not well document. Large flowering events have been recorded more than once per decade and are estimated to occur several times per century; but not all individuals will flower during these events (Esque 2022a, pers. comm.). The factors that determine the timing and frequency of flowering events is largely unknown and more research is necessary to determine if the timing and amount of precipitation, temperatures cues, or other factors influence flower production in Joshua trees. Flowering and seed production require a substantial amount of energetic resources and it may take individual trees at least 1 to 2 years to replenish their reserves to sufficient levels to support another flowering event (Borchert and DeFalco 2016, p. 831; Smith 2022, pers. comm.). The infrequent production of large crops of flowers and seeds could be an adaption to avoid the loss of all seeds produced to predation. This adaptation of plant communities to produce large quantity of seeds periodically rather than a low number of seeds annually is termed mast seeding or masting (Borchert and DeFalco 2016, p. 833). Recently, masting events were recorded in 2013, 2018/2019, 2022; there is variation across the range and single masting events typically do not occur range-wide. In 2013, 80 percent of the trees were in bloom on average, based on a study of 10 study sites across the Mojave Desert (St. Clair and Hoines 2018, p. 5). However, only 40 percent of the trees were blooming at cooler sites (Cima Dome and Walker Pass) and may have been due to the higher number of clones at these locations (Esque 2022a, pers. comm.). Monthly temperature maximum was found to be correlated with the number of trees in flower and the number of inflorescences per tree; but temperature is not believed to trigger flowering events. Interestingly, the seed production including the number of fruits per tree and seeds per tree were not correlated with temperature or precipitation.

3.4.2.1 Flowering and Pollination

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 have modified mouthparts known as maxillary tentacles, appendages unique to Yucca moths that function in collecting, transporting, and transferring Joshua tree pollen (Cole *et al*. 2017, p. 1). Female moths gather a ball of pollen in their maxillary tentacles, oviposit into the style, and actively transfer pollen to the stigma (Cole *et al*. 2017, p. 4).

Yucca moths emerge in late spring when Joshua trees flower and tend to be most active during the day (Figure 3-3; Cole *et al*. 2017, p. 3). Adult moths live for days to a week. They do not feed; their mouthparts are adapted for pollination instead of feeding (Smith 2022, pers. comm.). 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). The larvae hatch in the seed pod, presumably after a week or two when the seeds have matured (Smith 2022, pers. comm.), and feed on the fertilized seeds (Figure 3-4; Pellmyr 2003, p. 43). Larvae feed more or less sequentially through the seeds in a chamber of the seed pod and encountering an infertile seed causes the larvae to exit the pod and diapause, a period of suspended development typically during a period of unfavorable conditions (Ziv and Bronstein 1996, p. 64; Harrower and Gilbert 2018, p. 13). As a result, a higher number of infertile seeds may impact the size and survival of yucca moths. In the late summer, approximately 6 weeks after oviposition, yucca moth larvae burrow through the seed pod and fall to the ground below the Joshua tree. There they build a cocoon and diapause in the soil until conditions are conducive to pupation and subsequent adult emergence.

The obligate moths, *Tegeticula synthetica* and *T. antithetica*, are genetically distinct (Smith *et al*. 2008a, 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.

Both species of moth visit both Joshua tree species in the hybridization zone; but their larvae have decreased success on the non-preferred host and the hybrid trees have reduced vigor (Smith *et al*. 2009, p. 5225; Royer *et al*. 2016, p. 1731). Pollination in *Yucca brevifolia* is the result of *Tegeticula synthetica* in all parts of the range except the Tikaboo Valley where it can also be pollinated by *T. antithetica*, though seed set is reduced and the resulting hybrids have been characterized as having lower vigor (Starr *et al*. 2013, p. 9; Smith 2022, pers. comm.). Seed production in *Y. jaegeriana* is the result of pollination exclusively by *T. antithetica* since *T. synthetica* moths are unable to pollinate *Y. jaegeriana,* because their ovipositor is too long resulting in damage to the ovules in the floral ovary (Starr *et al*. 2013, p. 10). Once pollinated, Joshua trees produce large fruits, *Y. brevifolia* fruits can be as large as 9 cm long and 6 cm wide and weigh greater than 250 grams (Lenz 2007, p. 62).

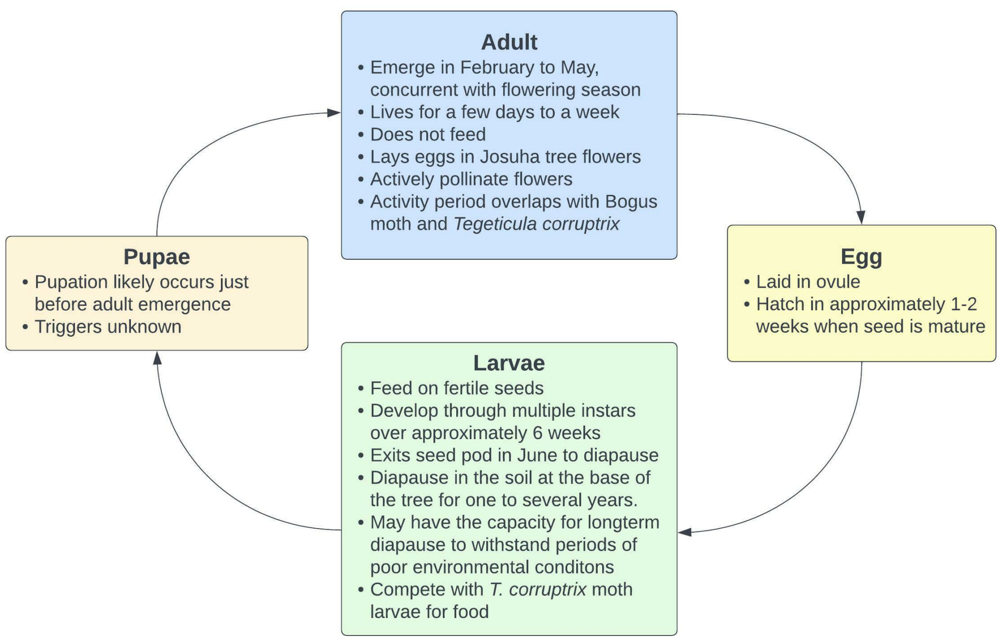

Figure 3-3. Yucca moth lifecycle.

Similar cues are presumed to trigger yucca moth adult emergence and Joshua tree flowering based on the synchronicity between events, though the exact triggers are unknown. Yucca moth larvae are presumed to diapause for more than a year under natural conditions, until conditions are suitable for adult emergence, and have been documented to diapause for 3 years under lab conditions (Smith 2022, pers. comm.). Another yucca moth species (*Prodoxus y-inversus*) was documented to emerge following 30 years in diapause (Powell 2001, p. 679), so we presume that the yucca moth species likely have the capacity to diapause for long periods, perhaps a decade or more.

Although this obligate mutualism has existed for thousands of years, adult and flower emergence are not always tightly linked; and there can be substantial temporal and site variability in flowering and the number of yucca moths (Smith 2022, pers. comm.). Moths have been absent or at low numbers during flowering events and emerge prior to flowering (particularly males). Within the approximately 1-month flowering season, moth abundance typically has more than one peak presumably as a measure to maximize the potential of encountering receptive flowers to lay eggs (Smith 2022, pers. comm.).

Beyond this overview, there is limited information available on the ecology of the two yucca moth species because they are small, cryptic, and only active for a short period of time. Based on research in JTNP, moth abundance (*Tegeticula synthetic*) was correlated with tree size, tree abundance, the number of flowers, and percentage of fertile seeds in *Yucca brevifolia,* except at extreme low and high elevations where sexual reproduction is minimal to absent (Harrower and Gilbert 2018, pp. 7–8). Low moth abundance and the absence of sexual reproduction was recorded at elevations less than 1,250 m and greater than 1,500–1,600 m, with higher moth abundance and sexual reproduction within this range. Climatic conditions at the elevation extremes and sites sampled are presumed to be unsuitable for yucca moths (Harrower 2022b, pers. comm.) Cold temperatures can limit insect development, but it is not clear what the thresholds may be or if moths were absent at higher elevations due the lack of flowering Joshua trees or other factors (Harrower and Gilbert 2018, p. 12). Apart from these elevation extremes, sites with more moths had greater reproductive fitness.

The research in JTNP described above characterizes potential variations in reproductive strategy and moth abundance at the southern limit of *Yucca brevifolia*; but different studies come to slightly different conclusions about what is driving reproductive success depending on what measure of reproduction was evaluated. St. Clair and Hoines (2018; p.14) found that warmer sites had increased reproduction based on the number of inflorescences and number of trees in bloom, though they did not observe a correlation with temperature and the number of seeds produced). Other range-wide studies found that lower elevation sites, characterized by hot and dry conditions, tended toward reduced reproduction due to reduced numbers of fruits, seeds per fruit, and a higher degree of seed predation (Smith 2022, pers. comm.). These results suggest that there may be a temperature threshold where increasing or extreme temperatures result in decreased reproduction; and we do not know that specific temperature limit. During a range-wide study of Joshua trees evaluating yucca moth abundance and reproduction across 16 sites sampling a range of elevations and abiotic parameters, both increased moth abundance and seed set were observed at higher elevations and latitudes than the JTNP research presented above (Smith 2022, pers. comm.).

Several other moth species utilize Joshua tree flowers for egg laying and as a larval food source. *Tegeticula corruptrix* (cheater yucca moth) also lays its eggs in Joshua tree flowers but does not pollinate the flowers (Smith 2022, pers. comm.). This species is abundant throughout the range of Joshua trees, competes with the obligate pollinators for larval resources, and can destroy the seed crop of individual trees. Two bogus moth species are known to oviposit on Joshua tree flowers, specifically the flower stalk (*Prodoxus sordidus)* or the outside of the fruit *(Prodoxus weethumpi*); but their larvae do not feed on the seeds and are not considered a direct competitor to the yucca moth (Smith 2022, pers. comm.). Bogus moth species do not pollinate Joshua trees. Joshua trees selectively drop flowers with excessive egg numbers from yucca moths, bogus moths or *Tegeticula corruptrix*, in effect reducing the predator load, and potentially increasing the probability of viable seed (Pellmyr and Huth 1994, p. 258).

3.4.2.2 Seed Set and Dispersal

Joshua trees produce a nonfleshy, large, indehiscent fruit on dense inflorescence panicles that typically matures in late May to June (Borchert and DeFalco 2016, p. 831; Smith 2022, pers. comm.). Like flowering, seed production is irregular (Esque *et al*. 2010, p. 11), and highly variable between years and across sites (Smith 2022, pers. comm.) with large seed crop productions occurring once or twice per decade (DeFalco and Esque 2014, p. 20). The seed crop produced by an individual tree is highly variable and depends on fruit crop size and seeds per fruit discussed further in **section 6.0 Factors Influencing Viability** (Waitman *et al*. 2012, p. 6; Borchert and DeFalco 2016, p. 833). Total seed production in *Yucca brevifolia* was estimated to be more than 100 times greater in 2013 (considered a masting event) than 2014, with both years of the study occurring during prolonged drought and below average rainfall (Borchert and DeFalco 2016, p. 833) due to the positive relationship between inflorescences per tree and fruits produced per tree (St. Clair and Hoines 2018, p. 5). The conditions that lead to high seed set are not well understood and are not explained by climatic conditions alone (St. Clair and Hoines 2018, p. 11). Pollination by the obligate moth species is presumed to be effective with the potential for 30–50 seeds per fruit (Lenz 2001, p. 65) when yucca moths are present. However, in JTNP, high numbers of infertile seeds were recorded at the lower and upper elevation extremes likely due to pollen limitation, the lack of pollinators, or other ecological or abiotic factors (Harrower and Gilbert 2018, pp. 7–8). Apart from these areas, sites with more moths had greater reproductive fitness (Harrower and Gilbert 2018, pp. 7–8) and the relationship between moth abundance and increased seed set has been observed throughout the range of Joshua trees including at high elevations (Smith 2022, pers. comm.).

Joshua tree seeds are indehiscent, requiring an outside force such as animals to open the seed pod (Figure 3-2; Lenz 2001, p. 62). There are five squirrel species documented to consume and potentially disperse Joshua tree seeds: Mohave ground squirrels (*Xerospermophilus mohavensis*), white-tailed antelope squirrels (*Ammospermophilus leucurus*), California ground squirrels (*Otospermophilus beechyi*), round-tailed ground squirrels (*Xerospermophilus tereticaudus*), and rock squirrels (*Spermophilus variegatus*)(Lenz 2001, p. 65; Borchert and DeFalco 2016, p. 832). Pinyon mice (*Peromyscus truei*), Merriam's kangaroo rats (*Dipodomys merriami*), agile kangaroo rats (*Dipodomys agilis*), and the San Diego pocket mouse (*Chaetodipus fallax*) cache seeds in their burrows in the ground, which facilitates germination (Borchert and DeFalco 2016, p. 832). Field caches contained between 3 and 6 seeds, depending on the species (Waitman *et al*. 2012, pp. 4–6). Seeds cached by rodents increased the likelihood of germination in the field and laboratory, particularly when buried 0.4–1.2 in (1–3 cm) deep (Waitman *et al*. 2012, pp. 4–6). Seeds not harvested by seed-caching rodents are presumed to have little to no chance of establishing a seedling (Vander Wall *et al*. 2006, p. 543).

Fruits have also been hypothesized to be dispersed by wind, ungulates, as well as, coyotes. As Joshua tree fruits dry out they are hypothesized to be transported by desert winds (Simpson 1975, p. 34), though subsequent research noted that wind dispersal is unlikely because wind speeds required to move Joshua tree fruits and seeds across the soil surface were higher than those typically found in the Mojave Desert (Waitman *et al*. 2012, p. 6). Seed dispersal may be carried out by ungulates documented to feed on Joshua tree fruits, including bighorn sheep, cattle (Lenz 2001, p. 64), mule deer (Keith 1982, p. 42), horses, and burros (Lenz 2001, p. 64). 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. Seeds of other plant species have been documented to be viable after passing through the digestive tracts of animals; but it is not clear if that is the case with these seed predators and Joshua trees. Recent observations of juvenile trees greater than 1,970 ft (600 m) from the nearest adult suggest that slightly further dispersal distances may be possible due to the mechanisms above (Cornett 2022a, p. 2). However, this has not been evaluated range-wide.

Dispersal of Joshua tree seeds is presumed to be limited by the movement patterns of its seed dispersers. White-tailed antelope squirrels for example can carry seeds 69 ft (21 m) on average from the seed source (Waitman *et al*. 2012, p. 4). Similar dispersal distances of 98 ft (30 m) on average and up to 187 ft (57 m) per flowering event were recorded for a suite of rodent granivores in a study in Clark County, Nevada, where the fates of individual seeds were tracked (Vander Wall *et al*. 2006, p. 541). The potential for dispersal and successful germination is tied to the magnitude of the flowering event and abiotic conditions. Scatter-hoarding by rodents is beneficial for Joshua tree if the seed crop is sufficiently large so that most of the seeds are not consumed and is presumed to be a strategy associated with masting events (Waitman *et al*. 2012, p. 6). In 2013, a masting year, mature fruits were observed to remain on the plant for a year, while in a fruit-poor year rodents removed the available fruits and seeds within 2 months (Borchert and DeFalco 2016, p. 833).

Germination can occur in as little as 24 hours once the seeds are mature (Lenz 2001, p. 62; Waitman *et al*. 2012, p. 6) and once buried, seeds have little capacity for dormancy. Joshua trees do not exhibit long term seed viability and a seed bank is not considered a habitat need as previously reported (Service 2018, p. 30). 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).

3.4.3 Joshua Tree Age Classes

The following Joshua tree age classes are described in terms of their abiotic requirements and age-specific risks to survival. The name and timeframe of each age class follow research conducted by USGS (Esque 2022a, pers. comm.).

3.4.3.1 Seedling

Seed germination is triggered by precipitation and generally occurs between September and May. Large germination and seedling emergence events are relatively rare and may occur as often as twice per decade due to the occurrence of masting events as well as favorable climate conditions (temperature and precipitation) necessary to support seedling survival (Reynolds *et al*. 2012, p. 1652; Waitman *et al*. 2012, p. 6; DeFalco and Esque 2014, p. 20) or as infrequent as a few times in a century (Wallace and Romney 1972, p. 191). Joshua tree seeds appear to germinate any time after a rain event (Went 1948, p. 250), though monthly precipitation in excess of 1.1 in (2.9 cm) is indicated as important for maintaining soil moisture for recruitment (Reynolds *et al*. 2012, p. 1652; Borchert and DeFalco 2016, p. 835). Seedling establishment is optimized under warm, wet conditions that encourage germination. 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). Seedling survival was optimal under night and day temperature regimes of 59° F:77° F (15° C:25° C) and 68° F:86° F (20° C:30° C) and survival declined at temperatures less than 50 to 68° F (10 to 20° C). Spring germinants have a higher risk of desiccation and mortality during the warm summer months (Esque 2022a, pers. comm.).

Mature seeds collected in the field yielded germination rates approximating 95 percent (Waitman *et al*. 2012, p. 6). Under laboratory conditions, seeds can germinate readily (within 24 hours) at 78.8 to 86° F (26 to 30° C), followed by rapid growth, when watered regularly and exposed to temperatures above 68° F (20° C) (Went 1957, p. 178). Germination did not occur below 68° F (20° C) (Went 1948, p. 251). However, in field germination trials, germination rates ranged between 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 seed predation, drought, and rapidly diminishing seed viability (Reynolds *et al*. 2012, p. 1652; Waitman *et al*. 2012, p. 6).

Joshua trees have higher germination and recruitment rates in association with nurse plants, perennial desert shrubs. Rodent seed caches below nurse plants remove seeds from the hot desert conditions and potentially increase survival through decreased desiccation (Waitman *et al*. 2012, p. 1). Several seed dispersers preferentially place seed caches at the base of shrubs (e.g., creosote bush; Borchert and DeFalco 2016, p. 835) that act as nurse plants that improve the probability of seedling emergence and survival (Reynolds *et al*. 2012, p. 1653; Waitman *et al*. 2012, p. 5) by creating a microclimate conducive to germination, higher nutrient levels, and by providing protection against herbivory. 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. 377). The connection between nurse plants and increased survival of Joshua tree's early life stages is well documented and seedlings, established individuals, and juveniles are rarely recorded outside of the drip line of a nurse plant (Reynolds *et al*. 2012, p. 1653; Esque 2022a, pers. comm.). In southern Nevada, researchers found that 92.8 percent of all seedlings were growing under various shrub species (Brittingham and Walker 2000, p. 377).

Joshua tree seedling survival appears to be limited by high temperatures and drought stress at lower elevations and by freezing temperatures and wind at higher elevations (Harrower and Gilbert 2018, p. 10). Survival of Joshua tree seedlings 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 (Figure 3-2; Cole *et al*. 2011, p. 143). Seedlings 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). Seedling survival rates can be reduced by a number of factors and are likely variable across the range. Under laboratory conditions seedlings kept at 40°–50° F (4°–10° C) and a 16-hour photoperiod for 2 months produced more leaves compared to established individuals kept at warmer temperatures, which could suggest that Joshua trees require annual exposure to low temperatures for optimal growth (Went 1957, p. 173). 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 the most leaves, with other photoperiods producing shorter and fewer leaves (McCleary 1973, p. 508). Other research have similarly concluded that seedlings may require several successive wet and/or cool years to survive (Cole *et al*. 2011, p. 147).

The roots of Joshua tree seedlings are colonized by a suite of arbuscular mycorrhizal fungi with species associations varying by plant community, elevation, and other abiotic conditions (Harrower and Gilbert 2021, entire). Mycorrhizal fungi provide plants access to mineral and micro-nutrients in exchange for carbon photosynthate produced by the plant. These relationships can confer benefits to inoculated plant species including increased growth and survival, and through improved disease and drought resistance. Joshua trees do not require mycorrhizal fungi but they can improve establishment and survival in the early age classes (Harrower 2022a, pers. comm.). A recent study of *Yucca brevifolia* mycorrhizal fungal associations in JTNP, indicate a potential for decreased growth at low elevations in the first few months following germination, due to the carbon demands necessary to build seedling's mycorrhizal network (Harrower and Gilbert 2021, p. 14). This additional resource demand may make seedlings at low elevation more vulnerable initially and contribute to decreased survival due to the hot, dry conditions that often occur at lower elevations. The potential impacts are anticipated to be strongest for seeds that germinate in the spring and must survive the warm summer months to become established. However, seedlings that become established at lower elevations tended to have strong mycorrhizal network that improves growth and survival relative to higher elevation fungal associations, based on research in JTNP.

3.4.3.2 Established Individual

The established individual life stage is discussed separately to acknowledge the time from germination to approximately 2 years of age, where individual mortality is high due to climatic conditions, and a suite of predators that browse on this vulnerable stage (Figure 3-4). Joshua tree individuals require adequate seasonal rainfall, moderate summer temperatures, a seasonal cold period, and summer rainfall over several years to become established. The development of a relatively large root system is hypothesized to allow young age classes to survive the dry season (Went 1948, p. 250). Also period of winter cold temperatures between 39.2–50° F (4°–10°C) for 2 months resulted in increased leaf growth at this life stage (Went 1957, p. 173). As a result, a cold period is presumed to be important to allow for growth and established during a period of reduced moisture and temperature stress.

Established individuals that are colonized by arbuscular mycorrhizae are shown to have an increased growth response due to the beneficial effects of improved nutrient uptake in JTNP (Harrower and Gilbert 2021, p. 14). At low elevation sites, these effects are more dramatic as the association moves from parasitism at initial germination to mutualism at approximately 9 months old, with sustained growth benefits relative to medium or high elevation fungal associations in the study area (JTNP). Established individuals are often less than 0.8–1.6 in (2–4 cm) tall after 2 years of growth and herbivory often results in mortality (Esque 2022a, pers. comm.). Herbivory at this stage is typically the result of jackrabbits, cattle, and deer and is discussed further in **Chapter 6.0 Factors Influencing Viability**.

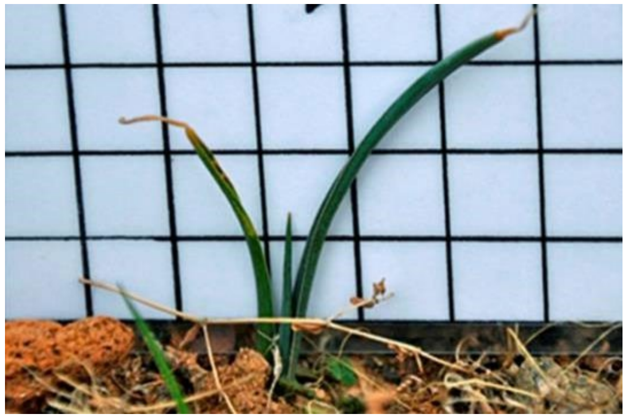

Figure 3-4. Size of a representative 2-year-old Joshua tree established individual with a 1-cm grid as a backdrop. Adapted from Reynolds *et al.* 2012. Used with permission.

3.4.3.3 Juvenile

The Joshua tree juvenile period occurs once it becomes established and before it is reproductively mature, from 2 to 30 years (Figure 3-5). Researchers found that plants less than 10 in (25 cm) tall had lower life expectancy and were more susceptible to herbivory especially in consecutive years of drought where other herbaceous forage was reduced (Esque *et al*. 2015, p. 89). *Yucca brevifolia* less than 3.3 ft (1 m) 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). Climate has a strong influence on early life stages of Joshua trees, either through drought stress or increased herbivory and predation during drought years (Esque *et al*. 2015, p. 89). The probability of survival increases as individuals grow taller particularly from heights of approximately 10 in (25 cm) to 3.3 ft (1 m) because herbivory is less likely to result in mortality (Esque 2022a, pers. comm.). Juvenile Joshua trees within or near the canopy of nurse plants are somewhat protected from herbivory (Reynolds *et al*. 2012, p. 1652; Esque 2022a, pers. comm.).

Figure 3-5. Juvenile Yucca brevifolia plants (foreground) at Lee Flat, Death Valley National Park, California. Photo by James Cornett. Used with permission.

3.4.3.4 Reproductively Mature Adult

Adult Joshua trees are reproducing (flowering), multi-branched individuals that can live over 100 years. Joshua trees are slow-growing and it can take up to 30 years for an individual to become sexually mature (Esque *et al*. 2015, p. 89). The estimated generation time is between 50 and 70 years, due in part to infrequent flowering events (Esque *et al*. 2015, p. 89). Adult trees are typically between 20 and 31 ft (6 and 9 m tall), but some can be much taller (Figure 3-6; McKelvey 1938, p. 119). In southwestern Utah, *Yucca jaegeriana* reach heights above 20 ft (6 m) and some trees were calculated to be over 300 years old (Gilliland *et al*. 2006, p. 202). In the Antelope Valley one *Y. brevifolia* was documented to be 80 ft (24 m) tall and 9 ft (2.7 m) in circumference (McKelvey 1938, p. 133). Growth rates in *Y. brevifolia* are variable between years, averaging 1.22 in (3.12 cm) per year, and are positively associated with precipitation (Esque *et al*. 2015, p. 85). 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 1.6 in/year (4 cm/year; Comanor and Clark 2000, p. 37) and 1.5 in/year (3.75 cm/year ; Gilliland *et al*. 2006, p. 202).

Figure 3-6. Adult Yucca brevifolia. Covington Flat, Joshua tree National Park August 2017. Photo by Felicia Sirchia, U.S. Fish and Wildlife Service.

The density of adult Joshua trees is highly variable across its range. In a study of 10 sites throughout the Mojave Desert, tree density was found to be negatively correlated with temperature and ranged from 20 trees per hectare in the warmer sites to the south and up to 280 trees to the northwest near Walker Pass (St. Clair and Hoines 2018, p. 6), though Walker Pass may include a high number of clones (Esque 2022a, pers. comm.).

In a study of Joshua tree reproduction in JTNP, reproductive output of mature Joshua trees varied across the elevation gradient sampled (Harrower and Gilbert 2018, entire). Peak sexual reproduction, growth and abundance occurred at intermediate elevations between 3,600–4,590 ft (approximately 1,100–1,400 m) based on tree height, number of branches, number of flowers and number of seed pods (Harrower and Gilbert 2018, p. 6). Sexual reproduction was absent at the lowest and highest elevations sampled based on the absence of flowers, fruits, pollinators, and seedlings, with a dominance of asexual, clonal reproduction particularly at the highest elevations over the course of a 2-year study. Although there was a relationship between tree size and several reproductive parameters, there was not a statistically significant relationship between tree size and the number of fertile seeds.

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). However, they are still susceptible to death due to herbivory and browsing, particularly in drought years. Jackrabbits and squirrels remove the outside bark because of its high moisture content. In the absence of this protection, trees experience moisture stress and can die. Similarly, gophers can hollow the inner core causing mature trees to topple, discussed further in **Chapter 6.0 Factors Influencing Viability** (Esque *et al*. 2003, entire)

3.5 Habitat and Ecological Needs

Throughout its range, Joshua trees generally occur on flats, mesas, bajadas and gentle slopes (alluvial fans; Figure 3-7); but they can also occur at lower densities on steep slopes and at higher elevations (Esque 2022a, pers. comm.). Both *Yucca brevifolia* and *Y. jaegeriana* occur between 33° 47’ 50”° to 38° 4’ 50”° latitude (Rowlands 1978, p. 56; Esque 2022b, pers. comm.) in southwestern U.S. desert ecoregions. Characteristic climate in these desert regions consists of long, hot summers and mild winters, with little precipitation that includes isolated thunderstorms in summer. Based on refined adult distribution data (discussed in more detail in **Chapter 4.0 Abundance and Distribution**), *Y. brevifolia* occurs between 1,922–8,775 ft (586–2,675 m) of elevation, approximately 1,000 ft (475 m) higher elevation than previously reported (Service 2018, p. 9; Esque 2022b, pers. comm.). The elevation range of *Y. jaegeriana* is slightly lower and occurs between 1,279–7,961 ft (390–2,426 m). The lower elevation limit of Joshua trees increases with latitude in response to shifting precipitation patterns and temperatures (Rowlands 1978, p. 55).

Figure 3-7. Example of Joshua tree habitat at Saline Valley in Death Valley National Park, photograph illustrates typical density of *Yucca brevifolia* across the landscape. Photo taken December 2017 by J. Wilkening, U.S. Fish and Wildlife Service.

3.5.1 Climate

Joshua trees occur almost exclusively in the Mojave Desert with the distribution extending into the Great Basin Desert to the north and the Sonoran Desert to the east. Joshua trees’ distribution is classified as a warm desert ecoregion where the magnitude and seasonality of precipitation are critical drivers of ecosystem processes. In general, the Great Basin receives more rainfall and has cooler temperatures than the Mojave Desert and the Sonoran Desert has warmer temperatures and higher summer rainfall. Average annual precipitation is highly variable and varies with elevation and to some degree with latitude (Tagestad *et al*. 2016, p. 388). Seasonality of precipitation also varies from west to east with different regions experiencing different ratios of winter versus summer precipitation (Wang *et al*. 2016, unpaginated).

Joshua trees appear to have adapted to the varying desert climate conditions given their occurrence across a wide range of vegetation communities (Rowlands 1978, p. 54), and elevation and precipitation gradients. However, the distribution of Joshua trees has some limitations. 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 in areas with extreme cold winter temperatures (Went 1957, p. 178; Rundel and Gibson 1996, p. 78). Warm season maximum temperatures and cold season minimum temperatures appear to limit the distribution of Joshua trees (Rowlands 1978, p. 179). The lower elevation 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).

We previously reported potential upper and lower temperature thresholds based on a physiology study conducted for *Yucca brevifolia* (Smith *et al*. 1983, entire; Service 2018, p. 28). We are no longer relying on the laboratory study to inform our understanding of the temperature regime Joshua tree is adapted to under natural conditions. The laboratory study evaluated impacts to cell integrity when individual leaves were exposed to extreme temperatures and suggested temperature tolerances between 12° F to 138.2° F (-11° C and 59° C). Although, we expect that Joshua trees' temperature tolerances occur within these extremes we do not have data to support specific thresholds. The temperature limits identified in the study neither represent Joshua trees thermal tolerance nor characterize appropriate growing conditions.

We rely on the current distribution of *Yucca brevifolia* and *Y. jaegeriana* to inform the temperature regime for Joshua trees (Table 3-1; Esque 2022b, pers. comm.). Data presented below are based on taking 100 randomly selected points within each analysis unit and summarizing applicable climate parameters available in the ClimateNA dataset for the period of 1991 to 2020 (Wang *et al*. 2016, unpaginated). The distribution of *Y. brevifolia* encompasses a summer temperature range of 69.4° to 87.3°F (20.8° to 30.7° C) based on the mean temperature in the warmest month of the year (MWMT; typically, July), with the potential for extreme summer temperatures between 100.9° to 120.4° F (38.3° to 49.1° C), based on the extreme maximum temperature (EXT) recorded over a 30-year period (1991–2020). Cold season conditions were characterized based on the mean temperature of the coldest month (MCMT: typically, January) and the extreme minimum temperature (EMT) recorded over a 30-year period (1991–2020) and ranged from 30.7° to 48.0° F (-0.7° to 8.9° C) and -22° to 21.2° F (-30° to -5.6° C) respectively.

Temperatures across the range of *Yucca jaegeriana* are similar but slightly warmer (Table 3-1). Summer temperature averaged 72° to 91.9° F (22.2° to 33.3° C) in the warmest months to extremes of 102.6° to 120.7° F (39.2 to 49.3° C). In the winter the coolest months ranged between 34.3° to 51.4° F (1.3° and 10.8°C) on average, with extremes between -17.5° to 21.0°F (-27.5° to -6.1°C) in the coldest months. Although both species experience extreme climate conditions as described above, we lack information on whether Joshua trees' vigor or survival would be reduced over a sustained period at either extreme. Similarly, rainfall was characterized for each species based on the mean annual precipitation (MAP) and mean summer precipitation (MSP) from May to September (Table 3-2). Annual precipitation for *Y. brevifolia* is higher than *Y. jaegeriana*. The relative contribution of summer rainfall to annual precipitation varied by species. Summer rainfall accounts for approximately 21 percent of the rainfall within the distribution of *Y. brevifolia* and 33 percent for *Y. jaegeriana*.

Table 3-1. The range of summer and winter temperatures across the distribution of *Yucca brevifolia* and *Y. jaegeriana*.

Temperatures	*Yucca brevifolia*	*Yucca jaegeriana*
Summer MWMT Min	69.4° F (20.8° C)	72.0° F (22.2° C)
Summer MWMT Median	79.3° F (26.3° C)	85.5° F (29.7° C)
Summer MWMT Max	87.3° F (30.7° C)	91.9° F (33.3° C)
Summer EXT Min	100.9° F (38.3° C)	102.6° F (39.2° C)
Summer EXT Median	110.4° F (43.6° C)	114.4° F (45.8° C)
Summer EXT Max	120.4° F (49.1° C)	120.7° F (49.3° C)
Winter MCMT Min	30.7° F (-0.7° C)	34.3° F (1.3° C)
Winter MCMT Median	42.1° F (5.6° C)	45.0° F (7.2° C)
Winter MCMT Max	48.0° F (8.9° C)	51.4° F (10.8° C)
Winter EMT Min	-22.0° F (-30.0° C)	-17.5° F (-27.5° C)
Winter EMT Median	3.2° F (-16.0° C)	10.6° F (-11.9° C)
Winter EMT Max	21.9° F (-5.6° C)	21.0° F (-6.1° C)

MWMT: Mean Temperature of the warmest month.
EXT: Extreme maximum temperature recorded over 30 years.
MCMT: Mean temperature of the coldest month.
EMT: Extreme minimum temperature recorded over 30 years.

Table 3-2. Mean annual and summer precipitation across the distribution of *Yucca brevifolia* and *Y. jaegeriana*.

Precipitation	*Yucca brevifolia*	*Yucca jaegeriana*
MAP Min	4.7 in (11.9 cm)	4.6 in (11.8 cm)
MAP Median	6.9 in (17.5 cm)	9.1 in (23.0 cm)
MAP Max	16.6 in (42.1 cm)	16.9 in (42.9 cm)
MSP Min	0.4 in (1.1 cm)	1.2 in (3.1 cm)
MSP Median	1.5 in (3.7 cm)	3.0 in (7.5 cm)
MSP Max	3.7 in (9.4 cm)	5.8 in (14.8 cm)

MAP: Mean annual precipitation.
MSP: Mean summer (May to September) precipitation.

Due to the warm temperatures and low rainfall that characterize Joshua trees' distribution, we used two climate parameters to characterize the level of drought stress that each species has experienced in the recent past (1961–1990 and 1991–2020; Table 3-3). Hargreaves climatic moisture index (CMD) measures the rate of evapotranspiration and is a reliable measure of drought conditions; higher values of CMD are indicative of increasing drought stress (Hargreaves and Allen 2003; Wang *et al*. 2016, unpaginated). CMD is variable across the range of each species and is influenced by latitude, elevation and topography (Figure 3-8). Joshua trees do not occur in areas of extreme CMD (greater than 1600), but there is evidence that the southeastern range of *Yucca jaegeriana* is currently and historically experiencing a higher degree of drought stress (1280) than the rest of the range.

Table 3-3. Drought parameters across the distribution of *Yucca brevifolia* and *Y. jaegeriana*.

Drought Parameters	*Yucca brevifolia* (units)	*Yucca jaegeriana* (units)
CMD Min	665.0	760.0
CMD Median	1117.5	1180.0
CMD Max	1431.0	1507.0
SHM Min	240.3	177.1
SHM Median	704.3	385.6
SHM Max	2692.5	954.5

CMD: Hargreaves climatic moisture index.
SHM: Summer heat moisture index.

Summer heat-moisture index [SHM; (MWMT/(MSP/1000)] is a seasonal ratio between precipitation and temperature and describes the contribution of summer rainfall in moderating heat and drought stress; higher values are indicative of more extreme summer heat stress (Wang *et al*. 2016, unpaginated). This parameter was selected because it helps characterize current recruitment conditions and the critical period for seedling establishment between spring and summer germination events. Currently, *Yucca brevifolia* experiences greater summer heat stress than *Y. jaegeriana* based on a combination of higher summer temperatures and reduced summer precipitation (Table 3-3). SHM in *Y. jaegeriana* is largely driven by monsoonal rainfall.

3.5.2 Soils and the Microbial Community

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, sandy soils or fine gravelly soils with varying amounts of gravel and rock that retain moisture (Rowlands 1978, p. 102; Harrower and Gilbert 2018, p. 4; Huning and Petersen 1973, p. 16). Joshua tree roots are colonized by a suite of arbuscular mycorrhizal fungi with species associations varying by plant community, elevation, and other abiotic conditions (Harrower and Gilbert 2021, entire). Mycorrhizal fungi provide plants access to mineral and micro-nutrients in exchange for carbon photosynthate produced by the plant. These relationships can confer benefits to inoculated plant species including increased growth and survival, and through improved disease and drought resistance. Based on a study in the southern limit of the *Yucca brevifolia's* range, fungal associations were demonstrated to improve nitrogen absorption and biomass in seedlings grown in green house conditions (Harrower and Gilbert 2021, p. 9). However, at lower elevations fungal associations negatively affected seedling growth in the first 3 months due to the large carbon demands of the mycorrhizae at that elevation (*Gigasporaceae*), which may constrain seedling establishment. By approximately 9 months, the association of low-elevation fungi conferred a greater benefit based on the growth response relative to seedlings with middle and high elevation fungal associations through greater access to soil nutrients (Harrower and Gilbert 2021, p. 15). We lack information on whether mycorrhizal associations are required for Joshua tree survival.

3.5.3 Vegetation

Joshua trees are commonly associated with a variety of other plant species depending on location. Although they are often the most visible species on the landscape because of their stature, they are typically not a dominant species in terms of vegetative cover (Rowlands 1978, p. 167; Esque 2022a, pers. comm.). Previous research indicated that "Joshua tree Woodland" is not considered a replicable vegetation community (Rowlands 1978, p. 54); but more recent research describes the Joshua tree woodland alliance in California as vegetation communities with greater than 1 percent cover of *Yucca brevifolia* and/or less than 1 percent absolute cover of *Juniperus* spp. or *Pinus* spp. in the tree canopy, with associations generally defined by the degree of disturbance from wildfire and grazing (Sawyer *et al*. 2008, pp. 301–303). We consider this delineation to also be appropriate for *Y. jaegeriana*. Depending on the classification system, geographic location, and type of disturbance, Joshua trees can be a component of the following vegetation communities: Sonoran-Colorado desert scrub, Mojave-Sonoran creosote bush scrubland, Mojave middle elevation desert, Mohave desert scrub, pinyon-juniper woodland. Specially they occur in vegetation associations with *Coleogyne ramosissima* (blackbrush), *Larrea divaricate* (chapparal), *L. tridentata* (creosote bush), *Artemisia tridentata* (Great Basin sagebrush), *Hilaria rigida* (big galleta grass), *Acamptopappus sphaerocephalus* (rayless goldenhead), perennial grasses, *Gutierrezia microcephala* (sticky snakeweed), *Cylindropuntia acanthocarpa* (buck horn cholla), and *Sphaeralcea ambigua* (desert mallow), the latter three being disturbance-related shrub species (Rowlands 1978, pp. 164–173; Sawyer *et al*. 2008, pp. 301–303).

In low-elevation (less than 3,937 ft; 1,200 m) areas, which receive the least amount of annual precipitation, *Larrea tridentata* and *Atriplex spinifera* (saltbush) tend to be dominant. Mixed woody scrub vegetation communities are found at middle elevations [3,937–5,905 ft (1,200–1,800 m)] and include *Coleogyne ramosissima*. The high-elevation [greater than 5,905 ft (1,800 m)], most mesic regions, are characterized by *Artemisia tridentata*, 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. (jointfir). The characteristic species in the Sonoran Desert includes *Carnegiea gigantea* (saguaro), *Parkinsonia* spp. (paloverde spp.), and *Larrea tridentata*.

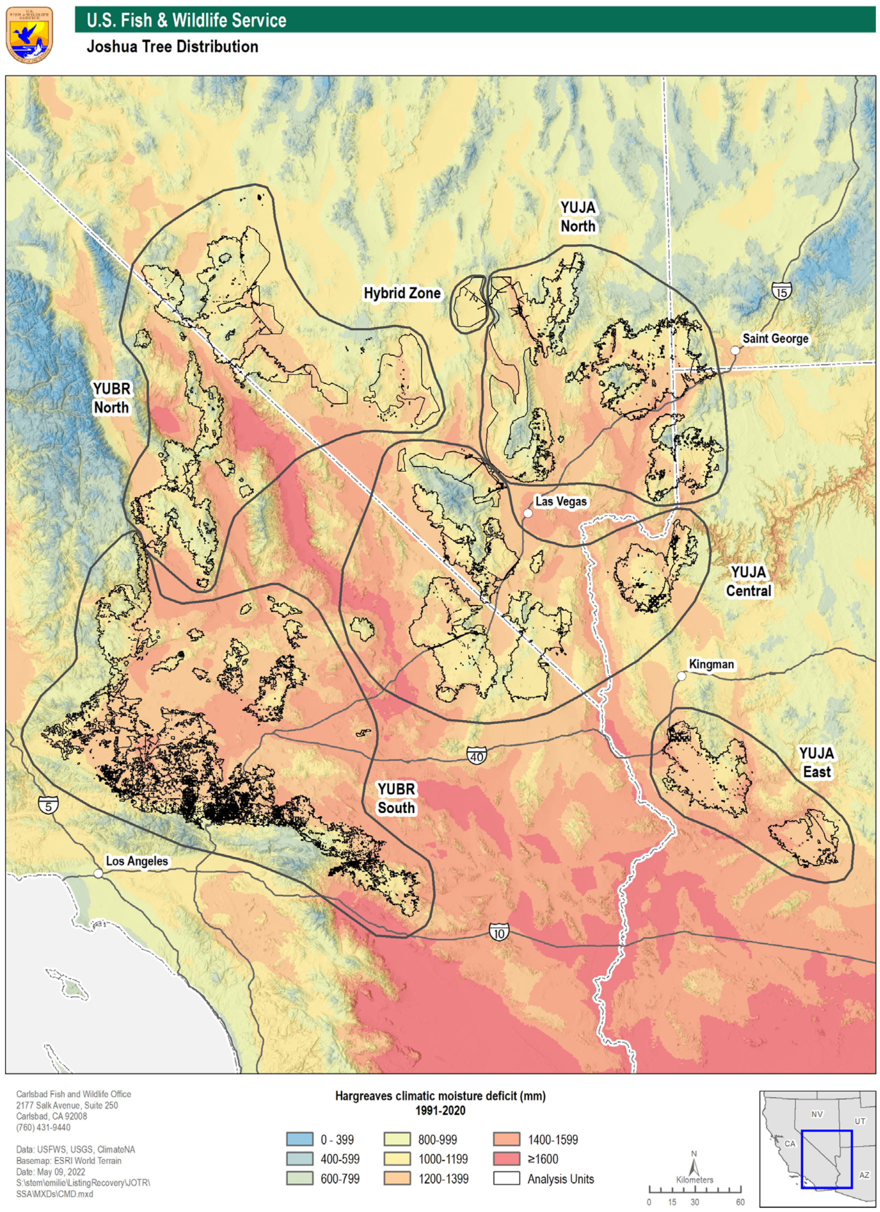

Figure 3-8. Hargreaves climatic moisture deficit (CMD) as a measure of drought stress across the range of *Yucca brevifolia* and *Y. jaegeriana*. Higher values are indicative of increased drought stress.

3.5.4 Ecoregions

Because Joshua tree habitat cannot be easily characterized by soil or vegetation type, we used the Environmental Protection Agency (EPA) ecological regions (ecoregions) to describe habitat variability including unique areas of geology, landforms, soils, vegetation, climate, and hydrology characteristics across the range of Joshua tree (Omernik 1987, entire; Omernik and Griffith 2014, p. 1254). We consider ecoregions to be a measure of the range of ecological heterogeneity where Joshua trees occur. Although defining ecoregions can be complex and rely on subjective criteria, they are a way to simplify and categorize the variability of ecosystems with similar characteristics (Omernik and Griffith 2014, p. 1251). Level IV ecoregions are the finest scale of this assessment that ranges from Level I to Level IV. Joshua trees occur in 33 geographically distinct Level IV ecoregions within eight Level III ecoregions: Mojave Basin and Range (Mojave Desert), Sonoran Basin and Range (Sonoran Desert), Central Basin and Range (Great Basin Desert), Sierra Nevada, Southern California Mountains, Western Transverse Range Montane Forest, Arizona/New Mexico Plateau, and Arizona/New Mexico Mountains (Figure 3-9). Most Joshua trees occur in the Mojave Desert ecoregion with the range extending into the Great Basin Desert ecoregion to the north and the Sonoran Desert ecoregion 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. In the northern part of the Joshua trees' range, the Mojave Desert transitions into the southern Great Basin Desert. The principal distinguishing feature of these two desert ecoregions is the presence of *Larrea tridentata* in the Mojave Desert and sagebrush steppe in the Great Basin Desert. The climate of the Great Basin Desert is like the Mojave Desert region in that it is variable and extreme in terms of rainfall and temperature; however, in general, the Great Basin Desert 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*, *Parkinsonia* spp., and *Larrea tridentata*. Temperatures are generally warmer and summer precipitation is higher in the Sonoran Desert than in all other parts of the Joshua tree range.

3.6 Dispersal and Migration

Joshua trees' dispersal and migration has been characterized by both its current short-distance movements associated with rodent seed dispersal and by its migration potential considering pre-historical range contractions. Scatter hording by seed-caching rodents is considered limited with mean dispersal distances of 98 ft [30 m; range from 41 to 186 ft (12.5 to 56.6 m)] from the source plant, though additional albeit limited dispersal likely occurs in secondary caches (Vander Wall *et al*. 2006, pp. 541–542; Waitman *et al*. 2012, pp. 4–6). Although high numbers of Joshua tree seeds are removed and seed-caching is thought to provide suitable conditions for germination, a study tracking the outcome of individual seeds found that only 0.36 percent of the cached seeds germinated. The study occurred in a drought year and that may have resulted in higher seed consumption than might occur in an average year or following a masting event. Seed dispersal through other means such as wind or ungulates occurs a small percentage of the time if at all and is not anticipated to contribute to larger dispersal distances than what is described above.

Similar rates of migration were characterized based on prehistoric data comparing Joshua trees' late Pleistocene [18,000 years-before-present (YBP)] range compared to the middle Holocene (about 8,000 YBP) that are similar to its current distribution (Cole *et al*. 2011, p. 141). The Joshua trees' historical range contracted northward along the southern edge of its Pleistocene range as climates warmed at the start of the Holocene (Cole *et al*. 2011, p. 141). Based on Pleistocene packrat middens, Joshua trees' migration during the Holocene is estimated to be approximately 6.5 ft/yr (2 m/yr)(Cole *et al*. 2011, p. 141). Both approaches support limited dispersal potential, on the average of 6.5 to 98 ft a year (2 to 30 m/yr) and the fossil record does not include any substantial northward expansion in the last 11,700 years (Cole *et al*. 2011, p. 145). Based on dispersal distances and historical migration rates, Joshua trees have limited capacity to disperse to and colonize new habitat where it has not previously occurred.

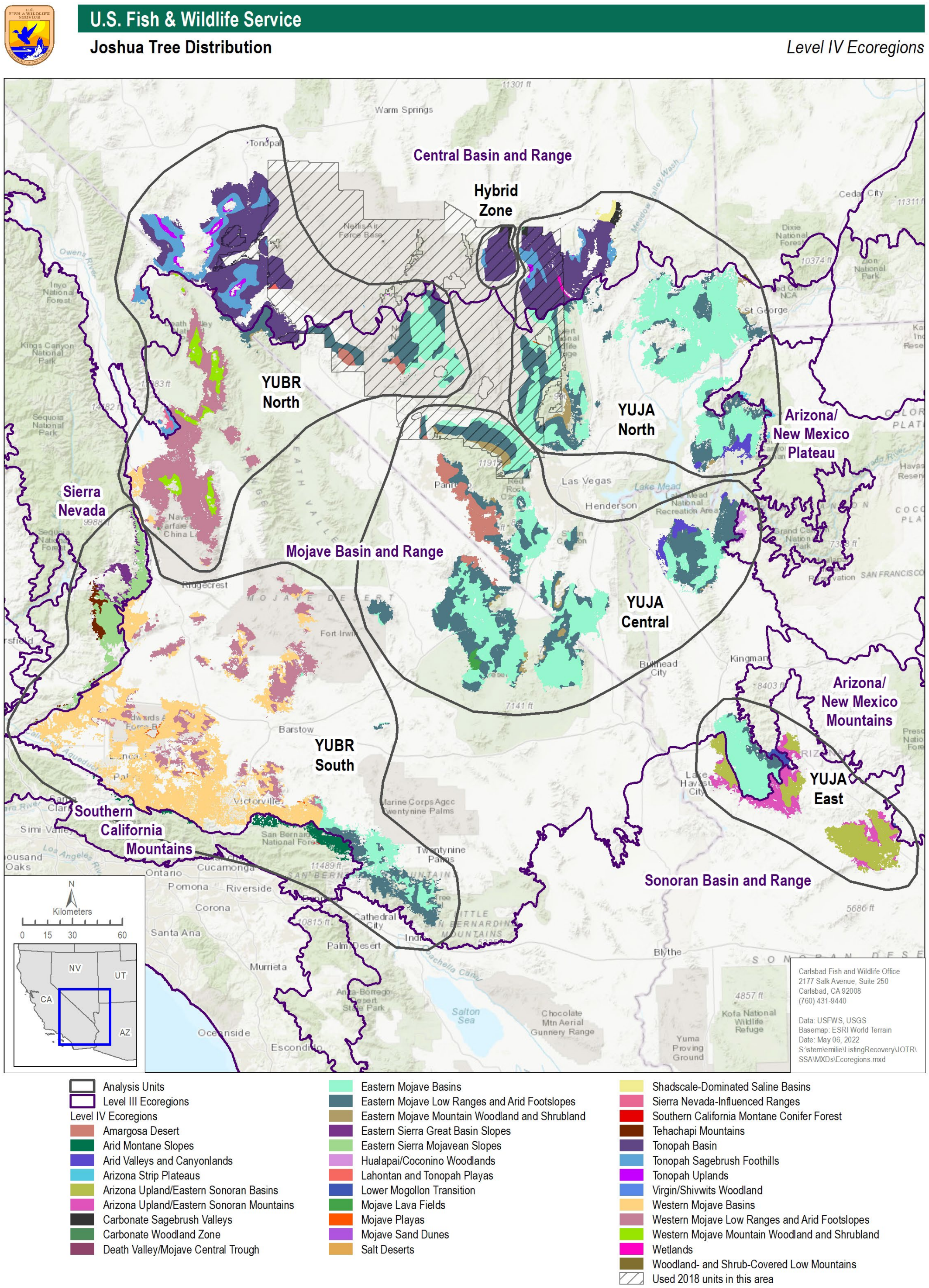

Figure 3-9. Joshua tree distribution and EPA Level III and Level IV ecoregions including areas occupied by *Yucca brevifolia* and *Y. jaegeriana*.

CHAPTER 4. ABUNDANCE AND DISTRIBUTION

4.1 Historical 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 climate conditions (temperature and precipitation patterns). Joshua trees' historical distributions are based on a USGS empirical study conducted throughout the range of *Yucca brevifolia* and *Y. jaegeriana* and is estimated at 9,642,136 ac (3,903,699 ha; Figure 4-1) (Esque 2022b, pers. comm.). All areas where adult Joshua trees were recorded are considered part of the historical range over an approximate time of 1900 to 1950, based on the lifespan of Joshua tree and development trends in the region. Presence, absence, and status (alive, dead, or ornamental) of adult Joshua trees was assessed through aerial interpretation and ground truthing of aerial imagery within quarter kilometer (2.6 million sq ft; 500 m by 500 m) grid cells. This method could not be applied in the northern portion of the species' range near Nellis Air Force Base in southern Nevada. In this area we used the distribution provided in our 2018 Joshua tree SSA that conveyed the general boundary and geographical limits of Joshua trees based on the available information at the time (Service 2018, p. 11).

4.2 Current Distribution

The current range of Joshua trees extends from northwestern Arizona to southwestern Utah west to southern Nevada and southeastern California (Figure 3-10). Joshua trees are currently distributed over several large discontinuous areas totaling 9.5 million ac [9,447,883 ac; (3,825,054 ha)] of a much larger region. The refined distribution presented in this SSA is based on a USGS empirical study conducted throughout the range of *Yucca brevifolia* and *Y. jaegeriana*, as described in the **section 4.1 Historical Distribution** above (Esque 2022b, pers. comm.). Areas of ornamental and dead Joshua trees were not considered occupied and were not calculated in the current distribution. Developed areas, based on the National Land Cover Database (NLCD) for high, medium and low intensity development, were excluded from the current distribution (NLCD 2022, unpaginated). Areas in the NLCD developed/open space designation were not automatically excluded; USGS conducted field surveys to delineate natural from ornamental stands of Joshua trees around development including many of the areas with this classification. The current range is approximately 194,253 ac (78,645 ha) smaller than the historical range and does not include 87,513 ac (35,430 ha) that is now developed. Similarly, 94,635 ac (38,314 ha) are no longer occupied by live Joshua trees, and 12,105 ac (4,901 ha) include ornamental trees outside of natural habitat and are no longer considered occupied. The current distribution is less acreage than we reported in the previous SSA [12,144,840 ac (4,906,749 ha)] that was based on records and reports available at that time (Service 2019, p. 14).

Yucca brevifolia occupies 4,417,276 ac (1,788,371 ha) and occurs almost exclusively in the Mojave Desert (Mojave Basin and Range). A small portion of its northern extent occurs within the Great Basin Desert (Central Basin and Range; Figure 3-10). It is unevenly distributed throughout southern Nevada and southeastern California. The southern extent of the range is located in JTNP's little San Bernardino Mountains. The northern extent of its range is located near Alkali, Nevada. The western extent is within and in the vicinity of 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 3-10). The current distribution is 112,829 ac (45,680 ha) smaller than the historical distribution.

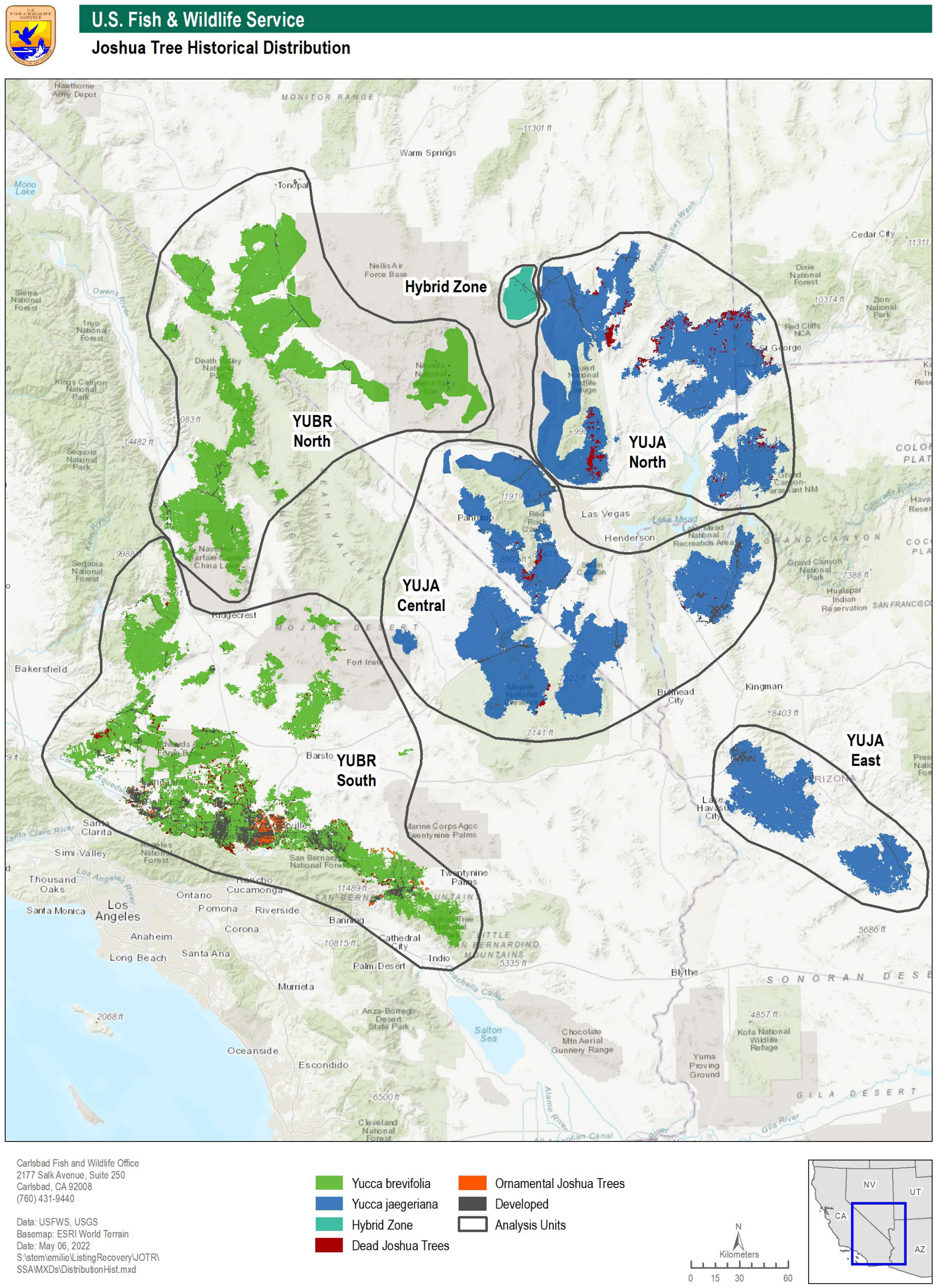

Figure 4-1. The historical distribution of Joshua trees (Esque 2022b, pers. comm.).

Yucca jaegeriana occupies 4,909,460 ac (1,987,636 ha) and occurs almost exclusively in the Mojave Desert (Mojave Basin and Range). A small portion of its northern range falls with the Great Basin Desert (Central Basin and Range) and a small portion of its eastern range falls within the Sonoran Desert (Sonoran Basin and Range and Arizona/New Mexico Plateau) in Arizona (Figure 3-10). 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 (Rowlands 1978, p. 53; Esque 2022b, pers. comm.). The current distribution is 81,245 ac (32,893 ha) smaller than the historical distribution.

In the Tikaboo Valley of southern Nevada, *Yucca brevifolia* and *Y. jaegeriana* overlap and have created a hybrid zone in an area of approximately 121,147 ac (49,047.5 ha; Figure 3-10) (Starr *et al*. 2013, p. 7; Royer *et al*. 2016, p. 1731; Esque 2022b, pers. comm.). The hybrid zone decreased slightly relative to the historical distribution; however, this area has a higher error rate because of the poor satellite imagery and lack of ground truthing.

4.3 Current Landownership and Land Use

Approximately 82 percent of the current distribution of Joshua trees is managed by Federal agencies, with the largest proportion managed by Bureau of Land Management (BLM; 53.6 percent) and the National Park Service (NPS; 10.7 percent) (Table 4-1; Figure 4-2). A larger proportion of the distribution of *Yucca jaegeriana* (88.7 percent) occurs on Federal land than *Y. brevifolia* (74.1 percent). Overall, state lands [including 9 state parks managed by California Department of Parks and Recreation (CDPR) and several properties managed by the California Department of Fish and Wildlife] and property owned by local jurisdictions account for 2.7 percent. Aside from Federal lands, private land is the largest percentage of ownership within Joshua trees' distribution accounting for a total of 15.3 percent including 24 percent for *Y. brevifolia,* and 7.4 percent in the current distribution of *Y. jaegeriana.* In addition to management and ownership, we considered the Joshua trees' distribution based on land use including development, military lands, renewable energy, water resources, working/production, and conservation (Table 4-2; Kern County 2012, 2013; County of San Bernardino 2016; NLCD 2022, unpaginated). These land use categories were derived from different datasets, therefore totals across all categories are not provided by species. The relative magnitude of each land use is described as a percentage of Joshua tree distribution. The main land use is working and production lands, used primarily for grazing (46 percent; Table 4-2), followed by conservation and recreation (40.2 percent); development (13.4 percent), and Department of Defense lands (8.8 percent; Table 4-1).

Table 4-1. Landownership within the distribution of Joshua tree [ac (ha)].

Ownership	*Yucca brevifolia* ac (ha)	*Yucca jaegeriana* ac (ha)	Hybrid Zone ac (ha)	Grand Total ac (ha)	Percentage of Joshua tree Distribution
Bureau of Land Management[1]	1,770,445 (716,779)	3,178,048 (1,286,659)	116,499 (47,166)	5,064,992 (2,050,604)	53.6
Department of Energy[1]	260,157 (105,327)			260,157 (105,327)	2.8
National Park Service[1]	498,566 (201,849)	516,716 (209,197)		1,015,282 (411,045)	10.7
U.S. Bureau of Reclamation[1]		4,345 (1,759)		4,345 (1,759)	0.0
U.S. Fish and Wildlife Service[1]		444,953 (180,143)		444,953 (180,143)	4.7
U.S. Forest Service[1]	55,353 (22,410)	75,993 (30,766)		131,346 (53,177)	1.4
Department of Defense[1]	690,554 (279,577)	135,615 (54,905)	4,658 (1,886)	830,828 (336,368)	8.8
Federal Total	**3,275,076 (1,325,942)**	**4,355,670 (1,763,429)**	**121,157 (49,051)**	**7,751,903 (3,138,422)**	**82.0**
Tribal[2]	5,505 (2,229)	3,067 (1,242)		8,572 (3,470)	0.1
State (Arizona)[2]		145,183 (58,779)		145,183 (58,779)	1.5
State (California)[2]	58,154 (23,544)	27,685 (11,209)		85,839 (34,753)	0.9
State (Nevada)[2]		277 (112)		277 (112)	0.0
State (Utah)[2]		13,242 (5,361)		13,242 (5,361)	0.1
Local[2]	714 (289)	288 (117)		1,002 (406)	0.0
Private[2]	1,077,971 (436,426)	364,304 (147,491)	52 (21)	1,442,327 (583,938)	15.3
Non-Federal Total	**1,142,344 (462,487)**	**554,047 (224,311)**	**52 (21)**	**1,696,443 (686,819)**	**18.0**
Grand Total	**4,417,419 (1,788,429)**	**4,909,717 (1,987,740)**	**121,209 (49,072)**	**9,448,345 (3,825,241)**	**100.0**

[1] Federal.
[2] Non-Federal.

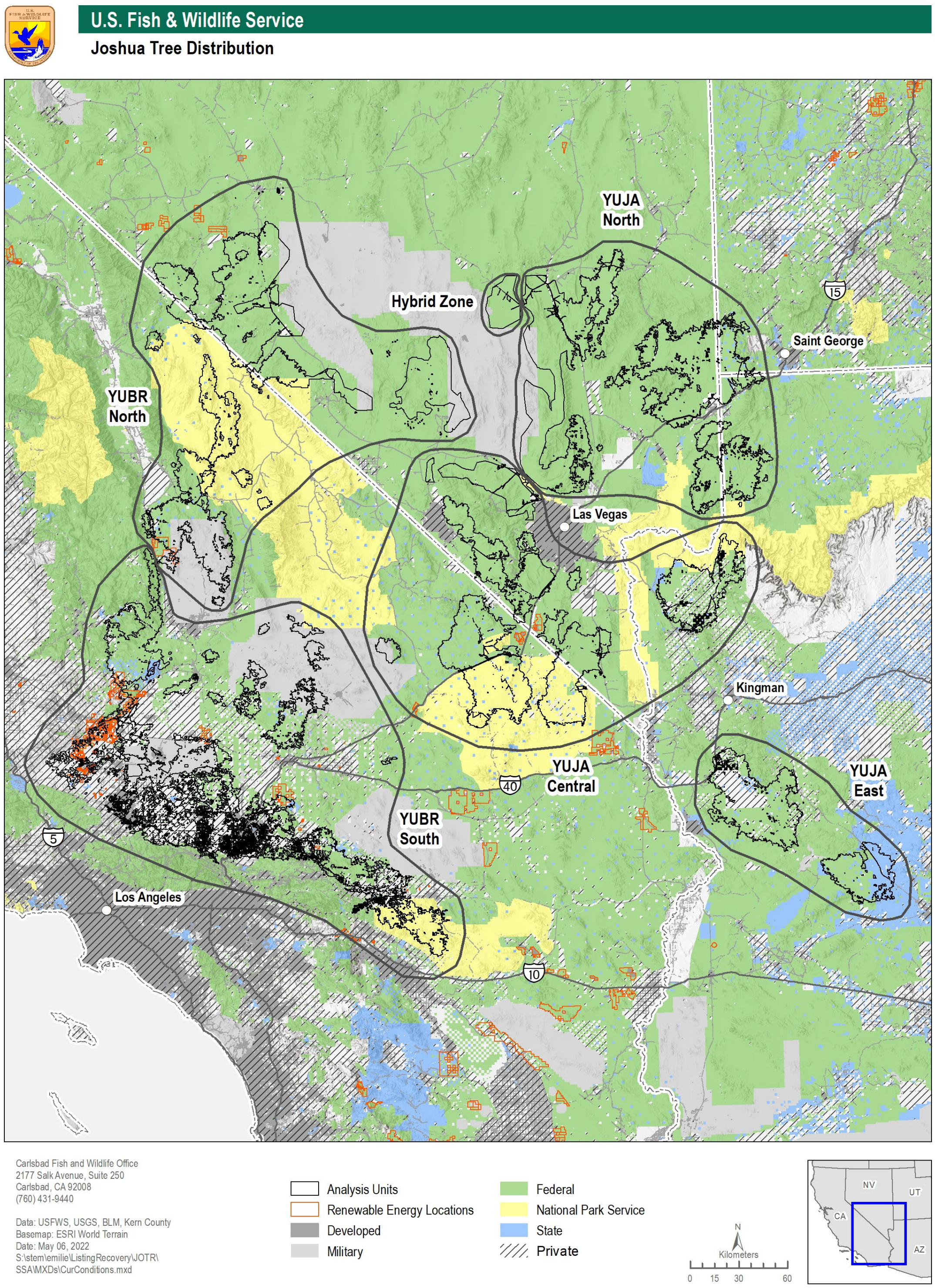

Figure 4-2. Land use and ownership within the current distribution of the Joshua trees (Kern County 2012, 2013; County of San Bernardino 2016; NLCD 2022, unpaginated).

Table 4-2. Major land uses within the distribution of Joshua trees.

Land Use	*Yucca brevifolia* ac (ha)	*Yucca jaegeriana* ac (ha)	Hybrid Zone ac (ha)	Total ac (ha)	Percentage of Joshua tree Distribution
Development	1,195,015 (483,812)	66,542 (26,940)	6,941 (2,810)	1,268,498 (513,562)	13.4
Military	690,554 (279,577)	135,615 (54,905)	4,658 (1,886)	830,827 (336,367)	8.8
Renewable Energy	84,154 (34,070)	0	0	84,154 (34,070)	0.9
Water resources	9,551 (3,867)	16,250 (6,579)	1,830 (741)	27,632 (11,187)	0.3
Working and Production	1,799,394 (11,187)	2,440,655 (988,119)	110,354 (44,678)	4,350,403 (1,761,297)	46.0
Conservation and Recreation	1,413,315 (572,192)	2,386,013 (965,997)	2,022 (819)	3,801,350 (1,539,008)	40.2

4.4 Current Abundance

There has not been a systematic, range-wide survey of the abundance or density of *Yucca brevifolia* or *Y. jaegeriana* to evaluate changes in abundance or density between historical and current conditions. We are able to characterize the current condition of Joshua trees' density based on several site-specific studies that span much of the geographic range (Esque *et al*. 2010; St. Clair and Hoines 2018; WEST Inc. 2021). We have summarized general trends by species below based on the site location relative to the current distribution used in this SSA.

Overall tree density across the distribution of Joshua trees is highly variable and ranged from approximately 1 to almost 161.9 trees/ac (400 trees/ha; Esque *et al*. 2010, p. 11; St. Clair and Hoines 2018, p. 6; WEST Inc. 2021, p. 5). With the exception of Cima Dome, California (76.9 trees/ac; 190 trees/ha), *Y. jaegeriana* sites had lower density on average [less than 28.3 trees/ac (70 trees/ha)] compared to *Y. brevifolia* (St. Clair and Hoines 2018, p. 8). For example, densities of *Y. jaegeriana* at Lake Mead National Recreation Area and Grand Canyon/Parashant National Monument averaged 12.5 to 15 trees/ac (30.8 to 37.2 trees/ha (Esque *et al*. 2010, p. 11). Densities of *Y. brevifolia* also varied widely 0.4 to 115 trees/ac (1 to 284 trees/ha) with the highest densities recorded at Walker Pass, California, though there was substantial variability between survey plots at this location and the count may have included clones (St. Clair and Hoines 2018, p. 6; Esque 2022a, pers. comm.). For sites sampled across the range of Joshua tree, there is a negative relationship between density and the average temperature in the warmest month based on the 30-year mean (St. Clair and Hoines 2018, p. 8). Although we project that tree densities may be higher in National Parks created in part to help preserve this resource, in the southern limit of *Yucca brevifolia* tree density varied substantially with estimates of 0.4 to 38.5 trees/ac (1 to 95 trees/ha; Esque *et al*. 2010, p. 11; St. Clair and Hoines 2018, p. 6; WEST Inc. 2021, p. 5). Using a combination of aerial imagery and opportunistic field assessments, adult tree densities within the southern limit of *Y. brevifolia* were estimated at 0.93 trees/ha (2.29 trees/acre) on average (WEST Inc. 2021, p. 5). Given the large distribution of the species, even small differences in density estimates would lead to large variations in abundance estimates obtained from multiplying density by area. Although there is a negative relationship between density and summer temperatures (St. Clair and Hoines 2018, p. 8), there is also high variability spatially throughout the range; therefore, we do not consider it appropriate to extrapolate across the range.

Although range-wide data and population trends are lacking, decreases in population size, tree vigor, and recruitment have been recorded within the southern range of *Yucca brevifolia*. At JTNP, mortality is outpacing recruitment with 2.2 dead trees for every Joshua tree seedling (Graver 2022, p. 1). JTNP also documented a 4.9 percent population decline and a 9 percent decline in adult trees over an approximate 12-year period. Similarly at Red Rock Canyon State Park, a 46 percent decline was recorded over a 21-year period, including declines in both juvenile and adult trees (Cornett 2019, p. 108). Similar monitoring data is not available rangewide; therefore we consider this information to be site-specific. It is also not clear if this data is indicative of a potential trend or natural variability in survival and recruitment.

4.5 Regions Defined for Further Analysis

We subdivided Joshua trees' current distribution into six regions based on differences in geographic distribution, species, vegetation, and temperature and rainfall amounts (Rowlands 1978, p. 72; Esque 2022a, pers. comm.). 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)]. The sixth analysis unit includes the Hybrid Zone in Tikaboo Valley between YUBR North and YUJA North, to distinguish the geographic area where both species and their pollinators overlap. These analysis units are distributed over a large area and individual Joshua trees are not equally distributed throughout (Table 4-3; Figure 2-2). Figure 4-3 summarizes the variability in climatic parameters across the different regions. We utilize these six analysis units to analyze both current conditions and future conditions in the subsequent sections of this SSA.

4.5.1 *Yucca brevifolia* North (YUBR North)

The northwest 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 3-11), which is the transition between the Great Basin and the Mojave Desert. The vegetation of this higher, cooler, and wetter zone includes single-leaf pinyon, juniper, and sagebrush. Within the Tonopah Basin, the understory includes warm season grasses, such as Indian rice grass and *Hilaria rigida*. Additional dominant plants include *Hilaria jamesii* (James' galleta), *Atriplex confertifolia* (shadscale), *Artemisia spinescens* (budsage), *Coleogyne ramosissima*, *Ambrosia dumosa* (white bursage), and *Lycium pallidum* (wolfberry) (Rowlands 1978, p. 74).

Table 4-3. Summary of analysis units used in this SSA

Population	Occupied Habitat ac (ha)	Proportion of Joshua tree Distribution (percent)	Elevation Range ft (m)	Level IV Ecoregions No. (No./100,000 ha)	Land Ownership (percent)
YUBR North	2,129,113 (861,989)	23	2,475-8,775 (754-2675)	16 (2)	F: 97.6 S: 0.51 P: 1.6
YUBR South	2,288,162 (926,381)	24	1,922-7,640 (586-2,328)	10 (1)	F: 52.3 S: 2.1 P: 45.6
YUJA North	2,065,476 (836,225)	22	1,540-7,961 (469-2,426)	16 (2)	F: 98 S: 0.9 P: 1.1
YUJA Central	2,089,163 (845,815)	22	1,626-7,627 (495-2,325)	7 (1)	F: 91 S: 1.9 P: 7.9
YUJA East	754,821 (305,595)	8	1,279-5,067 (390-1,544)	5 (2)	F: 59.8 S: 16.7 P: 23.5
Hybrid Zone	121,147 (49,047)	1	4,149-6,755 (1,265-2,059)	3 (6)	F: 100 S: - P: -

F: Federal
S: State
P: Private land ownership (Local ownership was less than 1 percent for all analysis units).

The elevation range of *Yucca brevifolia* in this population is between 2,475 and 8,775 ft (754 and 2,675 m). The median annual rainfall is 6.6 in (18.7 cm) and varies between 4.8 and 13.7 in (11.9 and 42.1 cm). Summer precipitation is 30 percent of mean annual precipitation (median value) and ranges between 11 and 56 percent. Within YUBR North*,* warm season temperatures are approximately 75.4° F (24.1° C; median) and range between 67.1° and 85.8° F (19.5° to 29.9° C); and the species has experienced extremes on the order of 98° to 114° F (36.7° to 45.5° C). Cold season temperatures are approximately 36.5oF (2.5oC; median) and range between 28.9° and 46.6° F (-1.7° to 8.1° C); and the species has experienced extremes on the order of -26.9° to 9.7° F (-32.7° to -12.4° C).

4.5.2 *Yucca brevifolia* (YUBR South)

YUBR South includes JTNP, California, to the south and extends north to the cities of 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, *Yucca brevifolia* trees occur within the Eastern Mojave Basins, Eastern Sierra Mojavean Slopes or Arid

Montane Slope Ecoregion (Figure 3-10). 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 include *Larrea tridentata* and *Ambrosia dumosa* and the higher elevations are characterized by junipers and pinyons (Figure 4-4). Additional dominant plants species include *Hilaria rigida*, *Coleogyne ramosissima*, *Stipa speciosa* (desert needlegrass), *Oryzopsis hymenoides* (indian rice grass), *Larrea tridentata*, and *Acamptopappus sphearocephalus* (goldenhead) (Rowlands 1978, p. 74). 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.

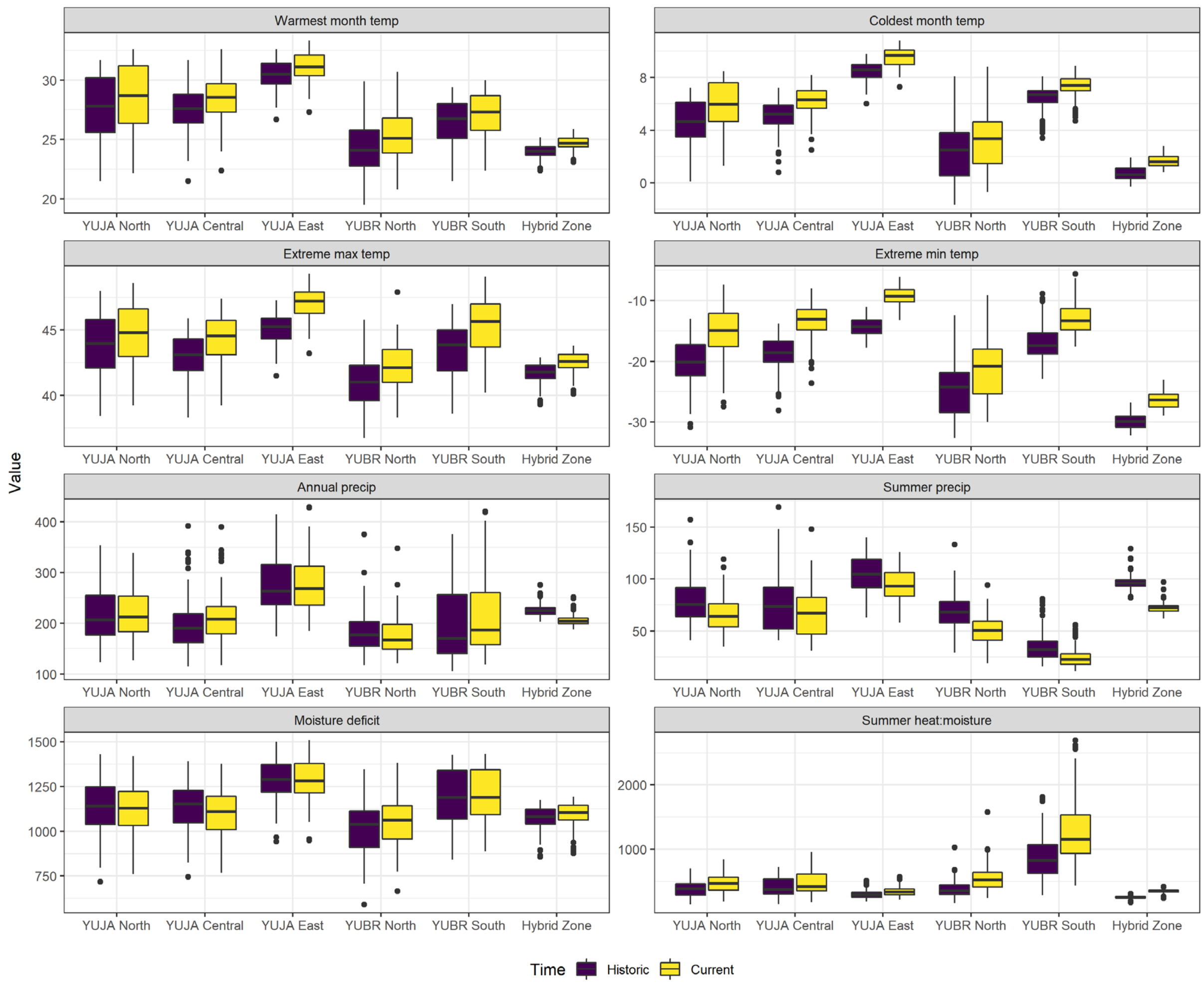

Figure 4-3. Median and variability of climate parameters across the regions analyzed.[1]

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[1] Climate parameters include mean temperature (°C) of the warmest month, mean temperature (°C) of the coldest month, extreme minimum temperature (°C) over 30 years, extreme maximum temperature (°C) over 30 years, mean annual precipitation (mm), mean summer precipitation (mm), summer heat-moisture index (higher values indicate hotter, drier years), and Hargreaves climatic moisture deficit index (mm; higher values indicate increasing drought stress). The historic period is from 1961–1990, and current period is 1991–2020.

Figure 4-4. *Yucca brevifolia* with junipers and sagebrush from Death Valley National Park (YUBR North). Photo taken December 2017 by J. Wilkening, U.S. Fish and Wildlife Service.

The elevation range of *Yucca brevifolia* in this population is between 1,922 and 7,640 ft (586 and 2,328 m). The median annual rainfall is 7.4 in (18.7 cm) and varies between 4.7 and 16.6 in (11.9 and 42.1 cm). Summer precipitation is 12 percent of mean annual precipitation (median value) and ranges between 6 and 30 percent. Within YUBR South, warm season temperatures are approximately 80.2° F (26.8° C; median) and range between 70.7° and 84.9° F (21.5° to 29.4° C); and the species has experienced extremes on the order of 101.5° to 116.6° F (38.6° to 47° C). Cold season temperatures are approximately 44.1° F (6.7° C; median) and range between 38.1° and 46.6° F (3.4° to 8.1° C); and the species has experienced extremes on the order of -9.2° to 16° F (-22.9° to -8.9° C).

4.5.3 *Yucca jaegeriana* North (YUJA North)

This *Yucca jaegeriana* population extends from the Desert National Wildlife Refuge north to Caliente, Nevada, and east to near 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 3-10) 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. Associated dominant plants include *Larrea tridentata*, *Ambrosia dumosa*, *Thamnosma montana* (Mojave desert-rue), sticky *Gutierrezia microcephala*, and *Krascheninnikovia lanata* (winterfat) (Rowlands 1978, p. 74).

The elevation range of *Yucca jaegeriana* in this population is between 1,540 and 7,961 ft (469 and 2,426 m). The median annual rainfall is 8.4 in (21.3 cm) and varies between 5 and 13.4 in (12.7 and 33.9 cm). Summer precipitation is 30 percent of mean annual precipitation (median value) and ranges between 16 and 56 percent. Within YUJA North, warm season temperatures are approximately 82° F (27.8° C; median) and range between 70.7° and 89° F

(21.5° to 31.7° C); and the species has experienced extremes on the order of 101.1° to 118.4° F (38.4° to 48° C). Cold season temperatures are approximately 40.4° F (4.7° C; median) and range between 32.2° and 45° F (0.1° to 7.2° C); and the species has experienced extremes on the order of -23.6° to 8° F (-30.1° to -13.3° C).

4.5.4 *Yucca jaegeriana* Central (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 3-10). These regions are characterized by alluvial fans, bajadas, basalt flows, hills, and low mountains that rise above the basin floors. The associated vegetation in this population is distinctly Mojavean at lower elevations but a Great Basin aspect is apparent at elevations above 5,900 ft (1,800 m). Dominant plants in this population include *Hilaria rigida*, *Coleogyne ramosissima*, *Ericameria cooperi* (Coopers goldenbush), *Opuntia acanthocarpa* (buckhorn cholla), *Gutierrezia microcephala*, *Hymenoclea salsola* (cheesebush), *Yucca schidigera* (Mojave yucca), *Ephedra nevadensis* (Nevada ephedra), and *Acamptopappus shockleyi* (Shockley's goldenhead) (Rowlands 1978, p. 74).

The elevation range of *Yucca jaegeriana* in this population is between 1,626 and 7,627 ft (495 and 2,325 m). The median annual rainfall is 8.2 in (20.8 cm) and varies between 4.7 and 15.4 in (11.8 and 39 cm). Summer precipitation is 32 percent of mean annual precipitation (median value) and ranges between 15 and 71 percent. Within YUJA Central, warm season temperatures are approximately 81.7° F (27.6° C; median) and range between 70.7° and 89° F (21.5° to 31.7° C); and the species has experienced extremes on the order of 101° to 114.6° F (38.3° to 45.9° C). Cold season temperatures are approximately 41.4° F (5.1° C; median) and range between 33.4° and 45° F (0.8° to 7.2° C); and the species has experienced extremes on the order of -18.6° to 7.2° F (-28.1° to -13.8° C).

4.5.5 *Yucca jaegeriana* East (YUJA East)

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 population encompasses the Arizona Upland and Eastern Sonoran Mountains and Basins ecoregions, with some areas within the Eastern Mojave Low Ranges ecoregion (Figure 3-10). The presence of *Carnegiea gigantea* (Figure 4-5), *Fouquieria splendens* (ocotillo), and *Parkinsonia* spp. 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), *Parkinsonia* spp., *Carnegiea gigantea*, and *Juniperus californica* (California juniper) (Rowlands 1978, p. 74).

The elevation range of *Yucca jaegeriana* in this population is between 1,279 and 5,067 ft (390 and 1,544 m). The median annual rainfall is 10.6 in (26.8 cm) and varies between 7.3 and 16.9 in (18.5 and 42.9 cm). Summer precipitation is 35 percent of mean annual precipitation (median value) and ranges between 22 and 47 percent. Within YUJA East, warm season temperatures are approximately 86.9° F (30.5° C; median) and range between 80° and 90.7° F

(26.7° to 32.6° C); and the species has experienced extremes on the order of 106.7° to 117.2° F (41.5° to 47.3° C). Cold season temperatures are approximately 47.5° F (8.6° C; median) and range between 42.8° and 49.6° F (6° to 9.8° C); and the species has experienced extremes on the order of -0.4° to 12° F (-18° to -11.1° C).

Figure 4-5. Photograh of Yucca jaegeriana from the YUJA East analysis unit on the Forepaugh Allotment near the Harcuvar Mountains in Arizona. Photo by James Holden, BLM Hassayampa Field Office. Photo taken September 2016.

4.5.6 Hybrid Zone in Tikaboo Valley

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; and the hybrids cannot be readily distinguished morphologically. This population is adjacent to YUJA North to the east and YUBR North to the west. The elevation range of this population is between 4,149 and 6,755 ft (1,265 and 2,059 m). The median annual rainfall is 8 in (20.4 cm) and varies between 7.4 and 9.9 in (18.8 and 25.2 cm). Summer precipitation is 35 percent of mean annual precipitation (median value) and ranges between 30 and 48 percent. Within the Hybrid Zone*,* warm season temperatures are approximately 75.2° F (24° C; median) and range between 72.3° and 77.4° F (22.4° to 25.2° C); and the species has experienced extremes on the order of 102.7° to 109.2° F (39.3° to 42.0° C). Cold season temperatures are approximately 33.1° F (0.6° C; median) and range between 31.5° and 35.4° F (-0.3° to 1.9° C); and the species has experienced extremes on the order of -26° to -16° F (-32.2° to -26.7° C).

CHAPTER 5. RESOURCE NEEDS

This section describes the resource needs that Joshua tree requires to be viable and describes the habitat, demographic, and species needs for *Yucca brevifolia* and *Y. jaegeriana*. The habitat needs include those abiotic and ecological parameters required to meet the basic life history functions and includes specific requirements for particular life stages. Demographic needs are those physiological and ecological processes required for the population to, at a minimum, be maintained but ideally to increase in abundance. Species needs are tied to the persistence of the species in terms of the number of viable populations, their distribution and their ecological and genetic diversity. All the resource needs are required for the species to be viable. A sufficient number of individuals must survive to constitute a population; that population must have the necessary numbers and diversity to be self-sustaining; and requires multiple resilient populations to persist in the face of changing environments and stochastic events. Thus, failure to meet habitat or demographic needs (on a large enough scale) can ultimately lead to species extinction.

Resiliency is the ability of a species to withstand changes in environment conditions, periodic disturbances, and demographic stochasticity. By evaluating population level characteristics such as demography and habitat quantity, quality, and distribution, we can evaluate the species' resiliency. The number of resilient populations, and their distribution and degree of connectivity, influences the species' redundancy. Similarly, the breadth of genetic or environmental diversity within and among populations influences the species' representation. Thus, for the species to sustain populations in the wild over time, the populations need to be able to withstand stochastic events (resiliency); the species as a whole needs to be able to withstand catastrophic events (redundancy); and the species as a whole needs to adapt to changing environmental conditions (representation).

In this section, we synthesize the information from the preceding sections to highlight the resource needs for Joshua trees to complete their life cycles (Figure 5-1). Joshua trees have specific habitat needs including suitable substrate, sufficient annual precipitation, summer precipitation, appropriate summer temperature range, a winter chilling period, abundant pollinators, rodent seed-caches, and nurse plants. To maintain resilient populations, the species require populations of an appropriate size and adequate reproduction to ensure sufficient abundance over time. Recruitment and future abundance are dependent on animals to open fruits and allow for seed germination and dispersal to maintain gene flow and to support recolonization after disturbance events. The habitat needs must be met for individuals to survive and reproduce. The demographic needs of a population must be met to ensure population resiliency and contribute toward the species' overall viability. Sustaining Joshua trees into the future will depend on the ability of populations to withstand annual variations in environmental conditions (resiliency), catastrophic events (redundancy) and the ability to adapt to changing conditions (representation).

5.1 Habitat Resource Needs

We assessed the best available information to identify the habitat resource needs to support individual fitness at all life stages for Joshua trees. For the purpose of this SSA, we considered the most significant habitat needs to include suitable substrate, annual precipitation, summer precipitation, appropriate warm season temperatures, winter cold period, abundant pollinators, rodent seed caches, and nurse plants. Table 5-1 summarizes the individual resource needs of Joshua tree by life stage and resource function. Figure 5-1 illustrates a conceptual model of the relationship between Joshua tree habitat and demographic population needs.

Table 5-1. Habitat needs for all Joshua tree life history stages.

Habitat Need	Life Stage	Resource Function
Suitable Substrate	Seedling, Established Individual, Juvenile, and Adult	Habitat, Nutrition
Annual Precipitation	Seedling, Established Individual, Juvenile, and Adult	Habitat, Nutrition, Reproduction
Summer Precipitation	Seedling, Established Individual	Habitat, Nutrition, Reproduction
Appropriate Warm Season Temperatures	Seedling, Established Individual, Juvenile, and Adult	Habitat, Nutrition, Reproduction
Winter Cold Period	Seedling, Established Individual, and Juvenile	Habitat, Nutrition
Abundant Pollinators	Adult	Reproduction
Rodent Seed-caches	Adult	Reproduction
Nurse Plants	Seedling, Established Individual, and Juvenile	Reproduction

5.1.1 Suitable Substrate

Joshua trees require the appropriate substrate to complete life history functions. Joshua trees primarily occur on alluvial fans and bajadas at the base of mountain ranges with a variety of old alluvia soil types of igneous origin. Alluvial fans and valleys are considered their preferred habitat; but they also can also occur in lower densities in rocky and steep terrain.

5.1.2 Annual Precipitation

A sufficient amount and frequency of annual and winter precipitation is necessary for photosynthesis, nutrient transport, germination, survival, reproduction, and growth at all Joshua tree life stages. Mean annual precipitation (MAP) between 1991 and 2020 is similar for both species and varies between 4.7 and 16.6 in (11.9 and 42.1 cm) across the range of *Yucca brevifolia* and 4.7 and 16.9 in (11.8 and 42.9 cm) for *Y. jaegeriana*.

5.1.3 Summer Precipitation

Sufficient summer precipitation is necessary to maintain soil moisture to promote germination and seedling survival. Greater than 1.1 in (2.9 cm) monthly precipitation in the months of July and August has been found to be an important threshold to maintain sufficient soil moisture for several days (Reynolds *et al*. 2012, p. 1652). To describe summer precipitation, we utilized the MSP over the months of May to September, for the years 1991 to 2010 (Wang *et al*. 2016, unpaginated). Within the range of *Yucca brevifolia* the MSP was 1.5 in (3.7 cm) and ranged from 0.4 to 3.7 in (1.1 to 9.4 cm). For *Y. jaegeriana* the median summer precipitation is higher than *Y. brevifolia* with a median of 3.0 in (7.5 cm) and a range from 1.2 to 5.8 in (3.1 to 14.8 cm). MSP represents a lower estimate of summer rainfall because it includes the months of May and June, and spring rainfall is typically limited throughout range of Joshua trees.

5.1.4 Appropriate Warm Season Temperatures

Warm season temperatures encourage flowering, reproduction, germination, and yucca moth activity; however, extreme warm temperatures contribute to drought stress and are correlated with reduced tree densities. To describe average warm season temperatures for each species we utilized the mean temperature of the warmest month from 1961 to 1990, as there is evidence that temperatures have increased in the recent past (Wang *et al*. 2016, unpaginated). To characterize the maximum temperatures the species have experienced and potential temperature thresholds for Joshua tree and the yucca moths, we used the extreme maximum temperature (EXT) over the last 30 years. *Yucca brevifolia* warm season temperatures are approximately 77.9° F (25.5° C; median) and range between 67.1° and 85.8° F (19.5° to 29.9° C); and the species has experienced extremes on the order of 98° to 116° F (36.7° to 47° C), though we do not have information on how long they can sustain these temperatures or if there will be impacts on vigor and fecundity. *Y. jaegeriana* summer temperatures are warmer on average at approximately 83.8° F (28.8° C; median) and range between 70.7° and 90.7° F (21.5° to 32.6° C); and the species has experienced extremes on the order of 101° to 118.4° F (38.3° to 48° C).

5.1.5 Cold Season Period

A cold season period between approximately 39.2° and 50° F (4° and 10° C) is hypothesized to reduce drought stress, encourage seedling establishment, and promote vegetative growth in established individuals and juveniles based on laboratory studies (Went 1957, p. 173), though we lack information on the duration of the cold period necessary to achieve these benefits under natural conditions. We acknowledge that this temperature range may provide optimal conditions for growth of early age-classes but may not necessarily be a requirement. To describe average cold season temperatures for each species we utilized the mean temperature of the coldest month from 1961 to 1999, as there is evidence that temperatures have increased in the recent past (Wang *et al*. 2016, unpaginated). *Yucca brevifolia* cold season temperatures are approximately 40.3° F (4.6° C; median) and range between 28.9° and 46.6° F (-1.7° to 8.1° C). *Yucca jaegeriana* cold season temperatures are slightly warmer on average at approximately 42.6° F (5.9° C; median) and range between 32.2° and 49.6° F (0.1° to 9.8° C).

5.1.6 Pollinators

Due to the obligate plant-pollinator mutualism, abundant yucca moth pollinators (*Tegeticula synthetica* and *T. antithetica)* are needed to maximize successful sexual reproduction, including high numbers of fertile seeds for yucca moth larvae development, and to account for the variability in the timing and abundance of flowering. No other pollinators successfully pollinate *Yucca brevifolia* or *Y. jaegeriana* other than the obligate yucca moths.

5.1.7 Rodent Seed-caching

Rodent seed-caching is required to remove mature fruits from the tree and mechanically open the indehiscent fruits to expose the fertile seeds for germination. Although this is a habitat requirement, seed-caching can result in higher seed predation under drought conditions because a larger number of seeds are consumed. Several rodent species locate their caches below shrubs that provide appropriate microclimate conditions to support germination and establishment of seedlings and also protect them from herbivores. We have no information on whether the seeds are viable after they are consumed and pass through the digestive system of rodents or other potential seed dispersers such as ungulates and coyotes.

5.1.8 Nurse Plants

Nurse plants are desert perennial shrubs where Joshua trees preferentially germinate largely due to rodent seed-caching below these same shrubs. We do not have any information to suggest that there is a species preference for nurse plants, beyond where a particular rodent species locates its seed-cache; and nurse plant species diversity will likely depend on the dominant shrubs within each region. Nurse plants improve germination and survival of seedlings, established individuals and juveniles by providing appropriate micro habitat conditions including higher soil moisture, decreased insolation, reduced soil temperatures, decreased evapotranspiration, increased nutrients, and lower wind desiccation. They also help protect seedlings, established individuals, and juveniles from herbivory.

5.2 Demographic Needs

We used the best information available to assess the resources, conditions, and demographic parameters that most influence the population resiliency of Joshua trees. Resiliency describes the ability of a population to withstand stochastic disturbance and is often positively related to population size and growth rate and may be influenced by connectivity among populations. If a species is resilient, we assume there exists sufficient suitable habitat in a condition to support stable populations such that the species can withstand stochastic events. Stochastic events that may impact Joshua tree populations include weather anomalies, such as years of low precipitation or heatwaves particularly early in the growing season, and wildfire. For Joshua trees to maintain resiliency to environmental variation and stochastic events, populations require adequate survival at all life stages such that a sufficient abundance of adult trees survive to reproduce. Sufficient recruitment is necessary to ensure that younger-age classes become established given the low seedling success and long lifespan. Sufficient abundance is important at all age classes given the higher susceptibility of seedlings, established individuals and juveniles to threats such as drought, herbivory and wildfire. Dispersal is important to maintain appropriate levels of genetic variation and to support recolonization of habitat following stochastic and catastrophic events. Figure 5-1 is a conceptual model that shows how the habitat needs discussed in the previous section influence the demographic needs, which ultimately affect population resiliency. Resiliency is discussed at the population level and representation and redundancy are discussed at the species level.

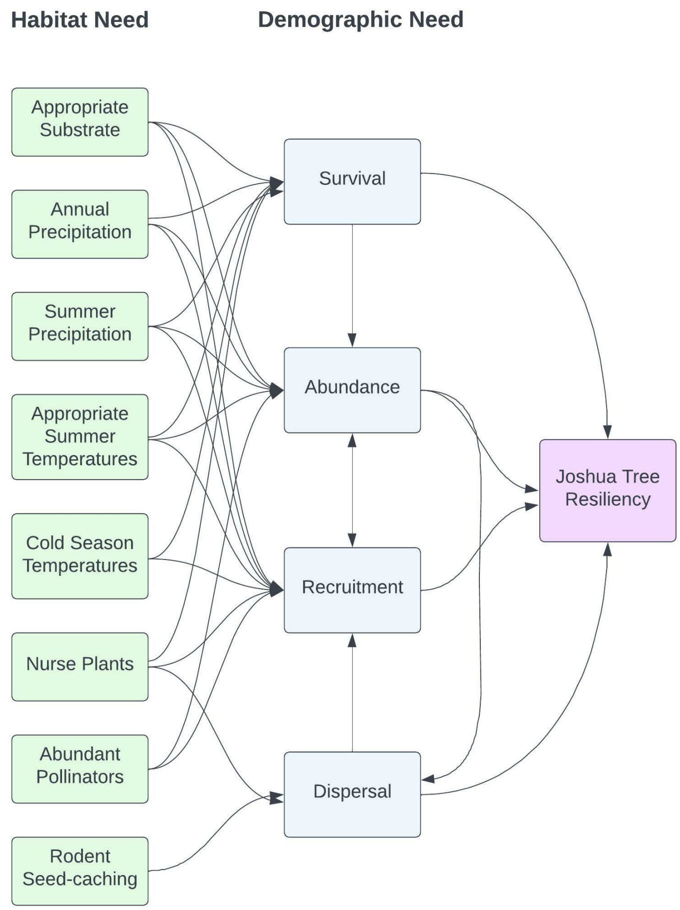

Figure 5-1. Conceptual Model.

5.2.1 Survival

Sufficient growth and survival at all life stages is required for an individual to reach sexual maturity and to maintain an abundant population. A diverse age structure is important for withstanding variability in climate and the pressures of threats such as drought, herbivory, and wildfire because young age-classes are more susceptible to mortality during these events than adults.

5.2.2 Abundance

Joshua trees require populations of sufficient abundance to be maintained over time with stable or increasing population growth. Sufficient abundance is achieved through survival of young age-classes to adult, successful reproduction, and recruitment to support the next generation. There must be adequate survival at all life stages to support an abundant adult population and sufficient density to support sexual reproduction. We currently lack a population viability analysis and information on the abundance at each age class required to maintain a resilient population. It is particularly difficult to model population growth due to the long generation time and rare reproduction opportunities.

5.2.3 Recruitment

Sufficient recruitment is necessary to maintain the population over the long term. Seed set in particular needs to be high enough to ensure future recruitment considering seed predation and the low percentage of viable seed that germinate and survive to reproduce.

5.2.4 Dispersal

Dispersal of propagules is important for gene flow to maintain appropriate levels of genetic variability. Dispersal also allows for potential colonization of sites following disturbance. Long-term dispersal and migration is a potential response to climate change across millennia, though dispersal is limited in Joshua trees.

5.3 Species-level Needs

We evaluated the redundancy and representation required for Joshua trees' viability.

5.3.1 Redundancy

Redundancy describes the ability of a species to withstand catastrophic events that would result in the loss of a substantial component of the species' total overall population and can be assessed based on the number of populations, their resiliency, distribution, and connectivity. Redundancy gauges the probability that the species can withstand or recover from catastrophic events and is improved as risk is spread among multiple, resilient populations. 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 number of regional resilient populations within the range. Populations should include abundant moderate to high quality habitat, with occupied habitat distributed across the range of hydrological and topographical variability.

Multiple resilient populations dispersed across the range of Joshua trees minimize the risk of impacts from catastrophic events such as prolonged, multi-year drought; severe herbivory events; or wildfire. Joshua trees evolved under arid desert conditions including droughts that may span 1 to 3 years and occasionally longer (4 to 7 years), approximately once every couple of decades (Wang *et al*. 2016; unpaginated). Based on this, we consider droughts longer than 7 years and less than 60 percent of average annual rainfall to potentially have large population-level impacts. We lack data on the impacts of historical, prolonged drought events of Joshua trees, but it has the potential to greatly increase the risk of extirpation of an analysis unit. Drought-exacerbated predation likely occurred historically at low levels and is only recently observed throughout the range of Joshua trees. We project the frequency of severe predation events to correlate with prolonged droughts, but we lack data on the population impacts of severe predation events. Currently, most of the distribution is experiencing a mega drought, including tree mortality and drought-exacerbated herbivory and predation, though the severity of the current event has only been monitored in the southern portion of *Yucca brevifolia's* distribution. Although droughts may occur range-wide, the different latitudes, elevations and aspects that Joshua trees occupy provide ecological complexity and the potential for climate refugia, areas of habitat projected to be climatically favorable where all the species needs are forecasted to be met, such that the entire distribution is not impacted equally. Wildfire events are more common in years following extreme rainfall due to the higher cover of invasive grasses that contribute to larger fires than occurred historically. The effects of wildfire on Joshua trees are variable and depend on the severity of the fire. Catastrophic wildfire conditions include both high severity fires and multiple, high frequency, low severity fires within the same habitat that can result in the death of Joshua trees and nurse plants and are sufficiently large that Joshua tree and native perennial shrub propagules are unlikely to readily recolonize the entire burn area.

5.3.2 Representation

Representation is the ability of a species to withstand and adapt to long-term changes in environmental conditions (i.e., significant changes outside the range of normal year-to-year variations). It is measured by the breadth of genetic or ecological diversity within and among populations and is used to evaluate the probability that a species is capable of adapting to environmental changes. Joshua trees representation or adaptive capacity was evaluated to assess the species ability to adapt to changing environments. In general, species adapt to changes in their environment by altering physical or behavior traits that allow them to persist in place or move in space to a new environment with suitable habitat conditions (Nicotra *et al*. 2015, p. 1270; Beever *et al*. 2016, p. 132; Thurman *et al*. 2020). Due to the lack of genetic information, the ability of Joshua trees to "persist in place" or "shift in space" was assessed following Thurman *et al*. 2020 including demographic, life history, distribution, movement, evolutionary potential, ecological role, and abiotic niche attributes.

Overall, Joshua trees are considered to have characteristics that promote moderate adaptive capacity based on high values for each species' broad distribution, evolutionary potential, and high reproductive output during masting events that are balanced by lower values for demographic parameters, requirement for specific pollinators, and limited dispersal ability (Appendix A). Both *Yucca brevifolia* and *Y. jaegeriana* are wide ranging species with a large distribution, range of suitable habitats and ecological variability that confers higher adaptive capacity. Genetic diversity may be considered high because both species are wide-ranging, though abundance and genetic diversity have not been explicitly evaluated to date. Individual trees also have the potential for high fecundity over the course of their long lifespan (150 to 300 years) based on seed set, though recruitment is anticipated to be low due to seed predation, low germination rates, and herbivory of young plants. Adaptive capacity is also considered lower due to Joshua trees' long lifespan, generation time, and age at sexual maturity which limit Joshua trees' ability to adapt to changing environments. Although clonal growth promotes persistence it is not considered to confer adaptive capacity. Adaptive capacity is also limited by short dispersal distance and reliance on the obligate yucca moth for pollination.

5.4 Summary of Species Needs

To summarize species needs, Joshua trees rely on habitat elements that include appropriate substrate, appropriate climatic conditions, abundant yucca moth pollinators, rodent seed-caches, nurse plants, and dispersal. Appropriate climatic conditions include adequate amounts of annual precipitation [4.7 and 16.9 in (11.8 and 42.9 cm)], summer monthly precipitation in excess of 1.1 in (2.9 cm) in the months of July and August, average summer temperatures based on the range experienced historically (67° to 91° F; 19.4° to 32.8° C), and winter temperatures between 29° and 50° F (-1.7° and 10° C), including a chilling period between 39.2° and 50° F (4° and 10° C). To reproduce successfully, Joshua trees need yucca moth pollinators, nurse plants, and seed-caching rodents. To maintain redundancy, numerous local populations need to be distributed widely across the landscape with some degree of connectivity to 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. In general, Joshua trees need multiple, large resilient populations distributed across the range of ecological variability to have the redundancy and representation to withstand catastrophes and adapt to environmental change given its moderate adaptive capacity.

5.5 Uncertainties

While we have used the best available information to determine the current status of Joshua trees throughout their range, we acknowledge our uncertainties in the species and resource needs that affect our current condition assessment below. We are aware of numerous on-going studies that are in progress that will improve our understanding of Joshua trees' ecology, genetics, and demographics; but that were not available for this SSA. USGS is currently revisiting survey plots within the National Park system initially assessed in 2007 and 2010 to characterize demographics and an assessment of tree health, to help characterize the current magnitude of the threat of drought and drought-exacerbated predation. Genetic variation in both Joshua tree species was sampled across their distribution and each species genome is being mapped. This effort also includes a common garden experiment to identify drought adapted genotypes.

Current Uncertainties:

1. Joshua tree population abundance data are needed to characterize total species abundance and to inform our understanding of resiliency and representation.

2. Population trends are needed to understand how the current population size compares to historical abundance, as well as, if there are regions that are declining more than other areas.

3. The level of recruitment necessary to sustain populations in the future due to the species' long lifespan, infrequent recruitment, and low establishment rates relative to seed production.

4. Genetic variation, regional population structure, and connectivity would help us determine if there are regions or genotypes that are important for maintaining sufficient representation.

5. Age-class mortality and survival would help us estimate the long-term resiliency of populations and help characterize the recruitment necessary to maintain population abundance.

6. Future climate model projections [Representative Concentration Pathways (RCPs)] with different socio-economic and mitigation assumptions contribute uncertainty to future climate conditions and our assessment of the species future status.

7. Incomplete understanding of the species' response to projected future climate conditions including potential physiological threshold that would help inform when future climate conditions may begin to impair survival and recruitment.

8. The potential for microclimates not identified in coarse scale climate modeling.

9. Information on yucca moth population abundance and trends is needed to describe how pollinator abundance varies across the range and from year to year, to inform if pollinators limit fecundity in Joshua trees and how pollinators may respond to the effects of climate change.

CHAPTER 6. FACTORS INFLUENCING VIABILITY

In this section, we describe the current conditions and current factors influencing Joshua tree. We provide a summary of potential threats affecting the species using the same habitat and demographic factors identified in **Chapter 3.0 Species Background and Ecology**. We consider the potential contributions of these threats and how these threats are negatively impacting the species' habitat and demography. We evaluate these threats in the context of (1) any existing regulatory mechanisms (Appendix B) that may reduce impacts to the species or its habitat, and (2) other existing efforts to protect or conserve the species. In this section, we identify current threats affecting Joshua trees. We use the term threat to refer to actions or conditions that may be or are reasonably likely to negatively affect individuals of the species directly or impact aspects of their ecology. Threats include actions or conditions that have a direct impact on individuals, as well as, those affecting individuals through alteration of their habitat or required resources. Threats may encompass the source of the action or condition or the action or condition itself. A threat's significance or magnitude depends upon a population-level assessment of the scope, intensity, likelihood, and immediacy of the threat as well as potential direct or indirect impacts it may have on Joshua trees or its habitat across all life history stages. Scope is defined as the spatial extent of a threat within the context of the species' range (localized, moderate, high or pervasive). Intensity indicates the magnitude of the impact on Joshua tree individuals (e.g., lethal or sublethal effects that may be negligible, low, moderate, strong, or severe). Likelihood describes the probability that the threat will impact Joshua tree in the foreseeable future. Immediacy refers to the time frame of the threat (ongoing, past, imminent, future). Threats may be reduced through existing conservation mechanisms or management activities and those mitigating measures are described below where appropriate. Below we outline the main threats currently affecting Joshua tree as informed by the recent past. These influences may impact individual, population, and species needs, and ultimately the viability of Joshua trees. The relationships between threats, sources, species' ecology and demographic parameters are illustrated in the effects pathway (Figure 6-1).

Within the landscape, several threats may disproportionally affect small-sized *Yucca brevifolia* and *Y. jaegeriana* plants and young age-classes as they may be more vulnerable to potential threats such as wildfires, prolonged drought, and herbivory (DeFalco *et al*. 2010, pp. 246–247;

Esque *et al*. 2015, p. 89). Because the life history, habitat needs, demographic 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 primary threats on both species: (1) habitat loss and degradation (from urbanization, military training, renewable energy, grazing, and off-highway vehicles); (2) invasive annual grasses; (3) increased risk of wildfire; (4) changing climate trends (e.g., increased temperatures and longer, more frequent drought periods); and (5) seed predation and herbivory (Figure 6-1).

Figure 6-1 is a conceptual model showing the relationships of the identified threats impacting the species' habitat and life history needs directly or indirectly at the population level. While we generally discuss these threats individually, threats can also occur simultaneously, thus additively affecting the resiliency of Joshua tree. Where different individual threats occur at the same time and place, we will describe how they may interact with one another below as well as in the future. Threats may be reduced through the implementation of existing regulatory mechanisms or other conservation efforts that benefit Joshua tree and its habitat. Regulatory mechanisms are summarized in Appendix B and are also discussed below throughout the text. Joshua trees' habitat needs (e.g., appropriate substrate, annual precipitation, summer precipitation, appropriate summer temperatures, winter cold period, nurse plants, abundant pollinators, and seed-caching rodents) will be discussed under **section 7.0 Current Conditions** and evaluated with respect to habitat quantity (quantity of occupied habitat) and habitat quality (invasive grass cover and ecological variability). The demographic need for survival and abundance will be evaluated using tree density and recruitment will be characterized by the percent of trees in the juvenile age class. We currently lack information to characterize dispersal for current conditions.

6.1 Habitat Loss and Degradation

This broad category includes threats that can physically disturb, damage, or kill Joshua tree plants or degrade or destroy the habitat required by the species. While most of the threats identified here are associated with human activities, some natural processes such as seed predation and herbivory (causing damage to or killing individual plants) may also impact the species and are discussed separately in **section 6.5 Predation and Herbivory**. The habitat modification category also includes several threats that increase the potential for invasive, non-native plant species to be introduced to Joshua tree habitat, thereby increasing competition for resources and fire danger, discussed in **section 6.2 Invasive Annual Grasses** and **section 6.3 Increased Risk of Wildfire.** Habitat loss and degradation across the range of Joshua tree primarily occurs through urbanization, development of renewable energy resources, military training, grazing, and off-highway vehicle (OHV) use. These potential threats may result in the permanent removal of plant cover, loss of individual trees, loss of soil structure, and habitat fragmentation. Each potential threat is discussed below along with applicable land management factors that could potentially alleviate these effects. In addition, the current legal framework is discussed below for Joshua tree based on ownership including Federal, state and city specific regulations and in Appendix B.

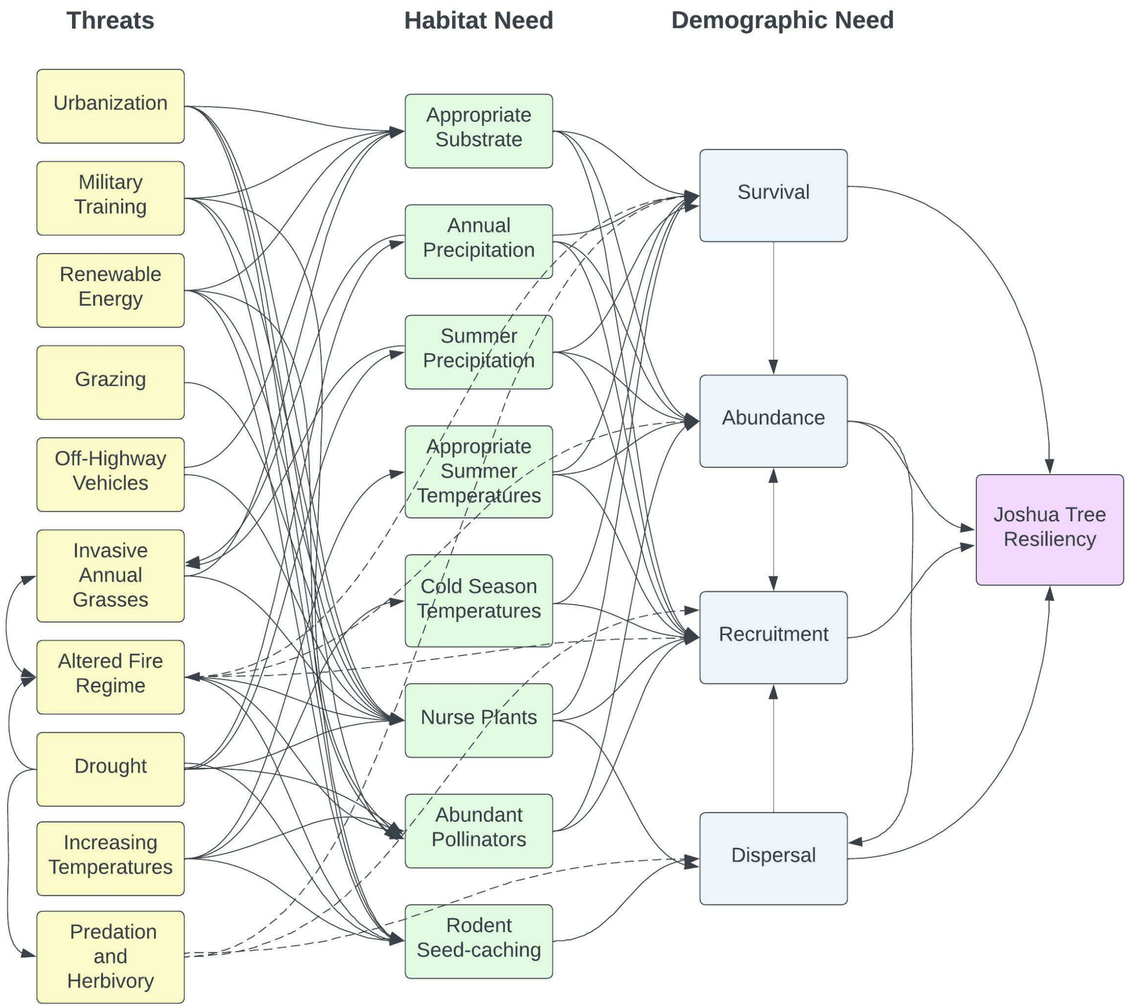

Figure 6-1. Joshua tree Effects Pathway. Threats are highlighted in yellow, habitat needs in green, demographic needs are in blue which all contribute to Josuha tree resiliency. Dashed lines indicate threats that impact demographic needs directly.

6.1.1 Urbanization

The Joshua tree distribution presented in this SSA excluded all existing low and high density development (NLCD 2022, unpaginated). In total 87,513 ac (35,430 ha) of development and 12,105 ac (4,901 ha) that currently includes Joshua trees used for ornamental plantings are no longer considered part of the Joshua trees' current distributions. For comparison, these areas represent approximately 1 percent of each species' current distribution on an acreage basis and are indicative of the portion of the distribution that is subject to edge-effects. In 2013, approximately 9 percent of the land uses in the Mojave Basin were associated with development and urbanization (Comer *et al*. 2013b, p. 12). Urbanization and development are a localized threat to Joshua trees that is more common near the urban-wildland interface in the vicinity of metropolitan areas. In particular, the southern limit of *Yucca brevifolia* (YUBR South) overlaps the cities of Victorville, Hesperia, Palmdale, Lancaster, and Ridgecrest; and the towns of Yucca

Valley, Apple Valley, and Antelope Valley and many of these jurisdictions have local ordinances to minimize impacts to Joshua trees. Recent development in these areas that we no longer consider part of the current distribution includes high density development where all habitat and trees are removed; but more often includes small 0.5 to 1.0 ac (0.2 to 0.4 ha) "ranchette" type developments often with large areas of undeveloped habitat in between. Future projections through 2025 forecasted a one percent increase in developed areas within the Mojave Desert over an approximate 12-year period; if this rate of growth is projected to the end of the century we would anticipate development to account for as much as 16 percent of the distribution of Joshua tree by 2097 and will be concentrated near existing metropolitan centers (Comer *et al*. 2013b, p. 11).

Across the range of Joshua trees, urbanization is highest within and near the range of *Yucca brevifolia* in both YUBR South and YUBR North. There are several regulatory mechanisms in place to avoid or mitigate negative effects to Joshua trees associated with development in California that are enforced by local jurisdiction; however, neither species is listed by any of the state endangered species acts where it occurs (Appendix B). As a result, we consider urbanization an on-going low magnitude threat, characterized by a localized scope and severe intensity.

6.1.2 Renewable Energy

Renewable energy development including solar, wind, and geothermal is the largest potential contributor to habitat loss associated with development in the Mojave Desert ecosystem outside of urban centers. Renewable energy development can contribute to habitat loss and direct tree mortality in occupied areas and may also result in habitat degradation and fragmentation depending on the type of project and extent of habitat impacts. Based on a review of the BLM's database on existing, approved and pending projects approximately 84,153 ac (34,071 ha; Figure 4-2) of occupied habitat includes current or pending renewable energy development (BLM 2016b, unpaginated; 2018a, unpaginated; 2018b; unpaginated). Most of renewable energy development occurs on private land (60 percent) followed by lands managed by the BLM (33 percent). Current renewable energy development comprises a relatively small proportion of the distribution of the western Joshua tree within YUBR North (1 percent) and YUBR South (3 percent), based on the current distribution.

Depending on the jurisdiction, planning has occurred to identify areas of potential renewable energy development including measures to avoid impacts to Joshua trees. In California, the Desert Renewable Energy Conservation Plan (DRECP) designates approximately 3-million ac (1.2-million ha) of development focus areas within the distribution of Joshua trees where it would apply a streamlined review process to applications for projects that generate renewable energy on BLM lands (BLM 2016a, p. 18). The DRECP contains measures to avoid removing individual plants by avoiding areas classified as Joshua tree Woodland (BLM 2016a, Vol II, pp. 3–55). This would reduce the number of individual trees and habitat potentially lost to renewable energy development under the DRECP. DRECP planning areas are located in YUBR South, YUBR North, and YUJA Central and the largest portion occurs within YUBR South including 70 percent of the planning area and 92 percent of the area of the analysis unit.

Similarly, BLM's Programmatic Environmental Impact Statement for Solar Energy Development in Six Southwestern States (Solar PEIS, also known also the Western Solar Plan) identifies areas for current and future renewable energy development (solar energy zones) in Arizona, California, Colorado, Nevada, New Mexico, and Utah (BLM 2012a, entire). The Solar PEIS also includes avoidance and minimization measures be incorporated into project design; but there are no measures to specifically avoid Joshua trees (BLM 2012a, p. 19). Salvaging Joshua trees for presumed translocation elsewhere was identified as a potential mitigation measure; however, we do not have information on the methods including the appropriate age-classes where this approach is most effective. There are also no areas of the current mapped distribution that overlap with BLM's current pending lease areas.

Renewable energy development is currently considered an on-going, high likelihood threat to Joshua trees with the potential for severe, localized effects. However, the extent of current renewable energy project areas within the Joshua trees' current distribution is small. As a result, the magnitude of the potential threat is low and limited to two analysis units: YUBR North and YUBR South. Renewable energy projects on BLM land in California include measures to avoid and minimize impacts on designated lands and several local jurisdictions in California have similar mechanisms in place; however, there are not similar regulations in place in Arizona, Nevada or Utah. We forecast that the future threats in YUBR South are imminent. There are currently 1,442,327 ac (583,938 ha) of *Yucca brevifolia* occupied habitat under private ownership, which represents 15 percent of the species' distribution. YUBR South has the largest proportion of private ownership (46 percent). We project that some amount of private land will be developed for the renewable energy in the future, with a higher likelihood of development occurring in YUBR South due to the availability of private land, proximity to metropolitan centers, and distribution of current renewable energy projects. However, there are currently no projections for future renewable energy development on non-federal lands.

6.1.3 Military Training

Several military bases occur within the distribution of Joshua trees including Edwards Air Force Base; Marine Corps Air Ground Combat Center Twentynine Palms (MCAGCC); Naval Air Weapons Station China Lake (NAWS China Lake); Fort Irwin National Training Center (Fort Irwin); and Nellis Air Force Base for a total of 830,828 ac (327,098 ha; 9 percent; Figure 4-2). Joshua trees occur at varying densities across these installations. They are widespread on Edwards Air Force Base but are less prominent or occur in isolated patches on the other installations. Military training is not anticipated to result in large scale impacts to Joshua trees and there are conservation measures in place to reduce impacts as described below.

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. INRMP specific measures for Joshua trees include conservation, where feasible; emphasis on using native plant species, including Joshua trees, for restoration of disturbed areas; inclusion of the species in base wide environmental awareness training for personnel; and inclusion of the species in vegetation and sensitive plant survey and mapping efforts and are discussed further by installation below.

The Edwards Air Force Base INRMP describes *Yucca brevifolia* as the “most prominent and widespread naturally-occurring treelike species on Edwards Air Force Base” (Barrios *et al*. 2017, 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 MCAGCC, 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 NAWS 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, pp. 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 (Air Force 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 (Air Force 2010, p. 120) with an identified goal to conserve unique plant communities (Air Force 2010, p. 123), which could provide incidental benefits to plants.

Portions of the YUBR South population overlap with the NAWS China Lake (U.S. Navy), Fort Irwin (U.S. Army), Edwards Air Force Base (U.S. Air Force), and the MCAGCC (U.S. Marine Corps). Portions of the YUBR North population overlap with the NAWS 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 and there are measures in place to minimize these impacts as described above.

Military training is a low magnitude, on-going potential threat to both *Yucca brevifolia* and *Y. jaegeriana.* Military training occurs within three of the analysis units, YUJA North, YUJA South, and YUJA West; and is greatest in YUBR North and YUBR South based on the percentage of acres under military or DoD ownership, 17 and 15 percent respectively. We consider the current potential threat to be infrequent and of low intensity, considering the avoidance and conservation measures in place at the different installations, as described above.

6.1.4 Grazing

Approximately 46 percent of the distribution of Joshua trees occur in areas with grazing allotments. The potential effects of grazing on Joshua trees include herbivory, fruit predation, trampling of young plants, browsing, and trampling of nurse plants, and surface soil disturbance. We lack information on whether these allotments are active, the intensity of grazing, and whether browsing by cattle could result in the death of individual trees. There is evidence that cattle, horses, and burros feed on Joshua tree fruits; but we do not know if the seeds are viable after they pass through their digestive tract. Cattle also feed on perennial shrubs, native annuals, and invasive grass species. There is evidence that cattle reduce invasion resistance by decreasing native plant cover and biological soil crusts (Reisner *et al*. 2013, p. 1046).

The potential threat of grazing is largely undefined. We project that there are low-level impacts to Joshua tree and its habitat throughout the range of Joshua tree including reduced cover of nurse plants and low levels of soil disturbance. It is also possible that cattle will browse on invasive annual grasses and reduce their cover; but we are not certain if there is a net benefit since cattle disturb the soil, which can promote invasive grasses. Grazing allotments occur in all six analysis units and account for 91 percent of the Hybrid Zone, 89 percent of YUJA East, and approximately 40 percent of the remaining analysis units (YUBR North, YUBR South, YUJA North, and YUJA Central). Grazing is an on-going, low magnitude threat. The potential impacts to Joshua trees are of low intensity but the impacts are pervasive, occurring across all analysis units. Grazing at high densities or for extended periods of time have the potential to facilitate invasive grass establishment (Chambers *et al*. 2019, p. 5) but we have no information to suggest if and where this might be occurring. We evaluate the effects of invasive grasses below in **section 6.2 Invasive Annual Grasses**.

6.1.5 Off-Highway Vehicle Use

Authorized and unauthorized OHV use likely occurs throughout a large proportion of the distribution of Joshua trees. OHV use generally occurs over a broad area and is more diffuse in nature, and typically does not result in complete habitat loss. Where use is most intense, disturbance and habitat loss can be severe, with vegetation largely removed—including nurse plants—and the soil structure is compromised; but we project high severity impacts to be limited in scope. Therefore, OHV use is considered a low intensity and magnitude potential threat that is on-going and moderate in scope, likely occurring to some degree across all analysis units.

6.1.6 Summary of Habitat Loss and Degradation

Overall, habitat loss and degradation by urbanization, military training, renewable energy development, grazing, and OHV use are considered low magnitude potential threats. The higher severity impacts of urbanization, military training, and renewable energy development are localized and have a limited scope in terms of acreage of impacts and the analysis units where they occur. They are also mitigated to varying degrees by regulatory mechanisms that contain existing avoidance and conservation measures as discussed above. Grazing and OHV use are more widespread, but the intensity of the impacts is low and more diffuse. In combination, YUBR South is most affected by habitat loss and degradation due to being closest to larger, metropolitan centers with increased development and edge-effects and the portion of the analysis unit designated to renewable energy development and military training.

6.2 Invasive Annual Grasses

Nonnative plant species, particularly annual invasive grasses, are spread by humans and anthropogenic disturbance, and have the potential to substantially degrade desert habitats. The potential effects include resource competition, perturbations in the natural disturbance and fire regime, plant community composition, vegetation structure, and a microclimate shift (Gordon 1998, p. 976). The severity of the nonnative plant invasion is dependent on the influence of local site factors including soil type, elevation, and disturbance history (Chambers 2000, pp. 1403–1412; Gelbard and Belnap 2003, p. 429; Chambers *et al*. 2007, entire; Davies 2008, pp. 113–114; Chambers *et al*. 2013, entire; Davies and Hulet, 2014, pp. 1–2). Disturbed soils provide additional safe sites for weed establishment, and the removal of the existing vegetation alleviates resource competition and promotes the successful invasion of weeds (Case 1990, pp. 9610, 9613–9614; Masters and Sheley 2001, p. 505; Novak and Mack 2001, p. 115; Leonard 2007, pp. iii, 61–62; Hornbeck 2019, entire). There are no published studies on the competitive effects of nonnative plant species to the germination, growth, and reproduction of the Joshua trees; however, we project competitive effects to increase with increasing nonnative plant cover and seedlings to be the most vulnerable life stage if they share the same root niche space and their soil water needs are high at a time of active nonnative plant growth and reproduction (Craine and Dybzinksi 2013, pp. 837, 839; Schwinning and Kelly 2013, pp. 888, 894; Gioria and Osborne 2014, pp. 5–6).

As nonnative plants become dominant in desert landscapes, they occupy the interstitial spaces between shrubs and persist throughout the summer and across multiple years increasing the fuel load (Brooks and Matchett 2006, p. 149). Fine fuels are typically provided by a wide variety of invasive herbaceous species including *Salsola* spp. (Russian thistle), *Erodium* spp. (filaree), *Brassica nigra* (black mustard), *Hirschfeldia incana* (shortpod mustard), *Sisybrium altissimum* (tumble mustard), *Lepidium latifolium* (perennial pepperweed), *Cirsium* spp. (thistle), *Carduus* spp. (plumeless thistle), *Centaurea* spp. (star thistle), and many others. While a wide variety of invasive plant species can degrade habitat and provide fine fuels for wildfires, the analysis from this point forward will only focus on invasive grasses. Invasive grass cover can increase rapidly in response to rainfall, particularly periods of high winter precipitation typical of El Niño oscillation events. Due to the cyclic nature of these events and variability in desert precipitation, high rainfall years are often followed by periods of extended drought resulting in higher biomass and dry fuel loads.

According to the BLM Rapid Ecoregional Assessment (REA) for the Mojave Basin and Range, invasive annual grass species and wildfire are the most significant threats to the Mojave ecosystem (Comer *et al*. 2013b, p. 11). There is a positive relationship between invasive grasses and the increase in the size and frequency of fires throughout the range of Joshua trees including the Mojave, Great Basin, and Sonoran Deserts (Brooks and Matchett 2006, p. 149). The invasive grass-fire cycle is well documented in the literature as a positive feedback loop, and invasive grasses alter the fire regime in several ways (discussed further in the **section 6.3 Increased Risk of Wildfire** below). Invasive grasses dry earlier in the season and can change the risk and timing of wildfire. They increase the potential for faster and larger wildfires by creating continuity of fuel loads and can lead to higher intensity fires. Invasive grass can also increase fire frequency because they recover quickly and have the potential to dominate the barren areas created after a wildfire, depending on site characteristics, the pre-disturbance ecological condition of the habitat, and the surviving cover of native plants within the habitat after disturbance events (Chambers *et al*. 2007, entire).

Within the range of Joshua trees, the primary invasive annual grasses are *Bromus madritensis* (foxtrail brome)*, Bromus rubens* (red brome), *Bromus tectorum* (cheatgrass), *Schismus arabicus* (Arabian schismus) and *Schismus barbatus* (Mediterranean grass). All the invasive annual grass species listed above occur throughout the range of Joshua trees. *Bromus tectorum* tends to occur at higher elevations and is especially invasive in the Great Basin Desert (Zouhar 2003, unpaginated). *Bromus rubens* is more dominant in the middle elevations of the Mojave Desert where Joshua trees generally occur. In their REAs, BLM modeled potential invasive grass cover across the Mojave and Great Basin Deserts based on 2011 records of 25 species, of which 94 percent of the records were *Bromus tectorum*, *Bromus madritensis* and *Schismus barbatus* (Comer *et al*. 2013b, p. 10). Modeled invasive grass abundance was categorized from no risk to high risk (greater than 45 percent cover).

Establishing thresholds for invasive grass cover that degrade Joshua tree habitat is complex and depends on the cover of native perennial shrubs, precipitation, and temperatures, all of which can vary by elevation and latitude. We also do not have direct evidence on how the soil moisture is modified in Joshua tree habitat under different levels of invasive grasses competition. In the literature, there is data to support an increased fire risk as invasive grass cover increases, though the relationship is not linear. An increase in the occurrence of fire (ignitability) was recorded in stands of *Bromus tectorum* and *Schismus barbatus* at greater than 1 percent cover (Fusco *et al*. 2019, p. 23597). The risk of fire increases at low levels of invasive grass cover and generally plateaus between 10 to 20 percent (Bradley *et al*. 2018, p. 1501; Fusco *et al*. 2019, p. 23597; Pastick *et al*. 2021, p. 23) and up to 45 percent (Link *et al*. 2006, p. 116), depending on the study area and on how risk is assessed. Although low levels of invasive grasses increase the probability that a fire will occur in the presence of an ignition source, higher cover is required for a fire to spread, continue to grow, and potentially alter the fire regime (Link *et al*. 2006, pp. 114–116). Under natural conditions, high fire risk in the Great Basin was defined as sustained fires that continued to grow in size 100 percent of the time and occurred at greater than 45 percent cover of *B. tectorum*; low risk was defined when wildfire occurred less than 50 percent of the time and generally occurred at cover of less than 15 percent (Link *et al*. 2006, pp. 114–117). Similarly, areas with higher *B. tectorum* cover (greater than or equal to 15 percent cover) had double the chance of maintaining fire spread than areas of lower cover (less than 15 percent cover; Bradley *et al*. 2018, p. 1500). Based on the combined information above, we considered all invasive grass model results from low risk (less than 15 percent cover) to high risk (greater than 45 percent cover) to indicate that invasive grasses pose a potential threat to Joshua tree and that the magnitude of the threat increases with increasing invasive grass cover (Comer *et al*. 2013b, p. 10). We defined high fire risk as areas with greater than 15 percent cover of invasive grasses based on the potential to generate and sustain large scale wildfires and low wildfire risk as areas with 1 to 15 percent cover of invasive grasses.

The BLM REA models of potential invasive grass cover characterize more than half (58 percent) of Joshua trees habitat as being at risk due to invasive grass cover, less than half (42 percent) was modeled as no risk (42 percent), and the remainder (approximately 8 percent of the range) was not modeled in that study (Figure 6-2). Of the areas at risk for invasive grasses, we categorized 37 percent [3,539,813 ac (1,432,511 ha)] as low risk based on the threshold of less than 15 percent cover and 12 percent [1,176,966 ac (476,301 ha)] as high risk (greater than 15 percent cover). The Hybrid Zone has the greatest proportion of habitat that we characterized as high risk (32 percent), followed by YUJA North (30 percent) and YUBR North (15 percent). Pockets of increased invasive grass occur throughout the range, and cover in excess of 45 percent totals 7 percent of the range of Joshua tree. Areas of dense invasive grass cover occurs along the interface between the Mojave and Central Basin Range ecoregion near the northern limit of *Yucca brevifolia* and *Y. jaegeriana* distribution (Figure 6-2). Throughout the range of Joshua tree, dense patches of invasive grasses are located where large fires have occurred and along the urban-wildland interface (Comer *et al*. 2013b, p. 79).

The studies referenced above were largely conducted on *Bromus tectorum*, which tends to occur in the higher elevation range of Joshua tree and in the Great Basin Desert north of the Mojave Desert. These areas are characterized by wetter conditions and higher native cover that contribute to increased fire risk because of greater biomass but also increased resiliency to invasion due to stronger competition for water and nutrients. (Chambers *et al*. 2007, entire; Davies 2008, pp. 113–114; Davies and Hulet 2014, pp. 1–2; Pastick *et al.* 2021, p. 11). Higher cover by native shrubs, rocks and soil crusts are also correlated with decreased fire risk in these environments (Link *et al*. 2006, p. 116) and help moderate invasion. In contrast, the middle elevations in the Mojave Desert have less perennial shrub cover and drier conditions that contribute to lower fire risk because of lower biomass, and have a lower resiliency to invasion because of lower resource competition. We expect that lower elevation Joshua tree habitats with lower native perennial shrub cover would require higher levels of invasive grass cover to provide the same degree of fuel continuity to sustain fire spread (Pastick *et al*. 2021, p. 12). The potential for introduction and expansion of invasive grasses may also be exacerbated through nitrogen enrichment associated with air pollution. Nitrogen enrichment has the potential to improve plant growth; but native desert perennials adapted to low nitrogen environments typically do not respond as readily to high nitrogen environments. In contrast, invasive annual grasses can readily adapt to high nitrogen environments and become dominant, leading to decreased species richness in native forbs and a less diverse vegetation community. In JTNP, 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 closer to urban centers and high levels of atmospheric ammonia in eastern areas (Allen *et al*. 2009, p. 13). We do not have information to describe the direct effects of increasing reactive atmospheric nitrogen on Joshua trees but we presume that it is contributing to higher invasive grass cover along the urban-wildland interface, particularly in YUBR South.

Although invasive grasses are highly pervasive and beyond the ability of any agency to eradicate, invasive grasses are managed on Federal and State lands to varying degrees. In particular, more than half of the distribution of Joshua trees occurs on BLM land (54 percent) and BLM has Best Management Practices (BMPs) for invasive and nonnative species that focus on the prevention of further spread and/or establishment of these species (BLM 2008, pp. 76–77). BMPs should be considered and applied where applicable to promote healthy, functioning native plant communities, or to meet regulatory requirements. BMPs include inventorying weed infestations, prioritizing treatment areas, minimizing soil disturbance, and cleaning vehicles and equipment (BLM 2008, pp. 76–77).

Invasive grass species are acknowledged as a primary threat to desert ecosystems and Joshua tree individuals and habitat because of their ability to deplete surface soil moisture and alter the severity, frequency, extent, and seasonality of fire (Brooks and Matchett 2006, p. 149). Invasive grasses are a low to moderate, pervasive, on-going threat that impacts the approximately half of Joshua trees' occupied habitat. The severity ranges from low to severe depending on the cover and is highest in the Hybrid Zone followed by YUBR North and YUJA North. We acknowledge that low levels of invasive grasses may increase the risk of fire (Comer *et al*. 2013b, p. 78) but are not necessarily an indication of an altered fire regime (discussed further below under the Increased Risk of Wildfire; Link *et al*. 2006, p. 114, 116;). In the future, invasive annual grasses are projected to expand their competitive edge over native species and are likely to benefit under conditions of drought, extreme precipitation events, increased CO_2 concentration, wildfire and atmospheric nitrogen (Archer and Predick 2008, p. 25). As a result, we generally project that the threat of invasive grasses will increase in the future, though extended droughts have also been hypothesized to result in decreased biomass and the potential to shift toward longer fire return intervals in the most arid areas of the Mojave Desert (Comer *et al*. 2013b, p. 7). However, invasive grasses respond quickly to extreme rainfall events and can become the dominant cover, particularly in areas with a history of disturbance such as wildfire.

6.3 Increased Risk of Wildfire

Wildfires are not historically a common occurrence in the desert regions of the southwestern U.S. Due to the low, discontinuous vegetative cover and fuel loads, wildfires are typically infrequent and small in size (Brooks and Matchett 2006, p. 148). Fire return intervals of greater than 100 years or more were estimated for *Artemisa tridentata* (Great Basin sagebrush) plant communities in the southwest and similar historical return intervals or longer are presumed for the range of Joshua trees (Mensing *et al*. 2006, p. 75). As a result, native scrub vegetation communities in the desert southwest, including Joshua trees, have not evolved with wildfire and are generally considered to not be well-adapted to fire (Abella 2010, p. 1249). Wildfires may cause numerous potential direct and indirect effects on Joshua trees and the associated plant community including immediate mortality, reduced survivorship over time, loss of nurse plants, reduced native cover, lower native plant diversity, damage to the protective bark-like periderm, mortality of the seed bank, and potential disruption of the pollinator and rodent communities, and are a source of disturbance that promotes colonization by invasive grasses. The magnitude of the impact varies with the size, severity, and frequency of wildfires, invasive grass cover, and weather conditions both during and after the event (DeFalco *et al*. 2010, entire; Barrios *et al*. 2017, entire; Klinger *et al*. 2019, p. 10).

Wildfires, particularly moderate to high severity burns, have the potential to result in immediate mortality and reduced survivorship over time. Above normal precipitation in 1998 and subsequent increased annual grass cover fueled many large fires in the Mojave Desert (DeFalco *et al*. 2010, p. 243). The mortality rate for burned *Yucca brevifolia* was approximately 80 percent compared to 26 percent for unburned plants. Plants that were shorter than 1 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 declined within 5 years. 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 JTNP in 1978, and 64 to 95 percent mortality at various sites evaluated 1 to 47 years after fires that occurred in the Mojave and Sonoran Deserts (Minnich 1995, p. 102; DeFalco *et al*. 2010, p. 246). 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 ac (202 ha) of *Y. brevifolia* habitat in 1999 indicated that the number of trees post-fire was stable (Barrios *et al*. 2017, pp. 1–3), though few, large adult trees were observed to be alive in areas that burned also burned in 2005 (Barrios and Watts 2017, p. 4). The initial data collected before the fire relied on methods that could have underestimated juvenile Joshua trees, and it is possible that individuals in young age classes could have died but were not accounted for in the study. More recently, a 4-fold decrease in tree densities was observed 15 years after the large wildfires in 2005 in the southwest Utah, even after accounting for resprouting (St. Clair *et al*. 2022, p. 4). Joshua trees may respond to wildfire by producing resprouts from the trunk or from the primary roots (Minnich 1995, p. 102; Barrios *et al*. 2017, p. 103; St. Clair *et al*. 2022, p. 4). Resprouting requires the tree or root system to be viable post-fire. Resprouting is more frequent in areas with a high proportion of surviving trees and decreases with increasing burn severity (Minnich 1995, p. 103).A high degree of charring on the trunk and in the tree canopy contributes to higher mortality. Researchers suggest that the susceptibility of fire differs for the two Joshua tree species; *Yucca brevifolia* may avoid substantial damage due to its stature, while *Y. jaegeriana* trees may be more severely impacted due to their shorter stature, extensive branching and higher biomass near the ground surface (Minnich 1995, p. 102; Cornett 2022b, p. 186). The persistent, dead leaves near the base of the trunk of Joshua trees, particularly *Y. jaegeriana*, also allows fire to more readily spread upward (Minnich 1995, p. 102). These factors may have contributed to the mortality of the 1.3 million *Y. jaegeriana* trees that died in the 2020 Dome fire in the Mojave National Preserve; only 7–9 percent of the trees had sufficient vigor to survive through resprouting (Cornett 2022b, p. 188).

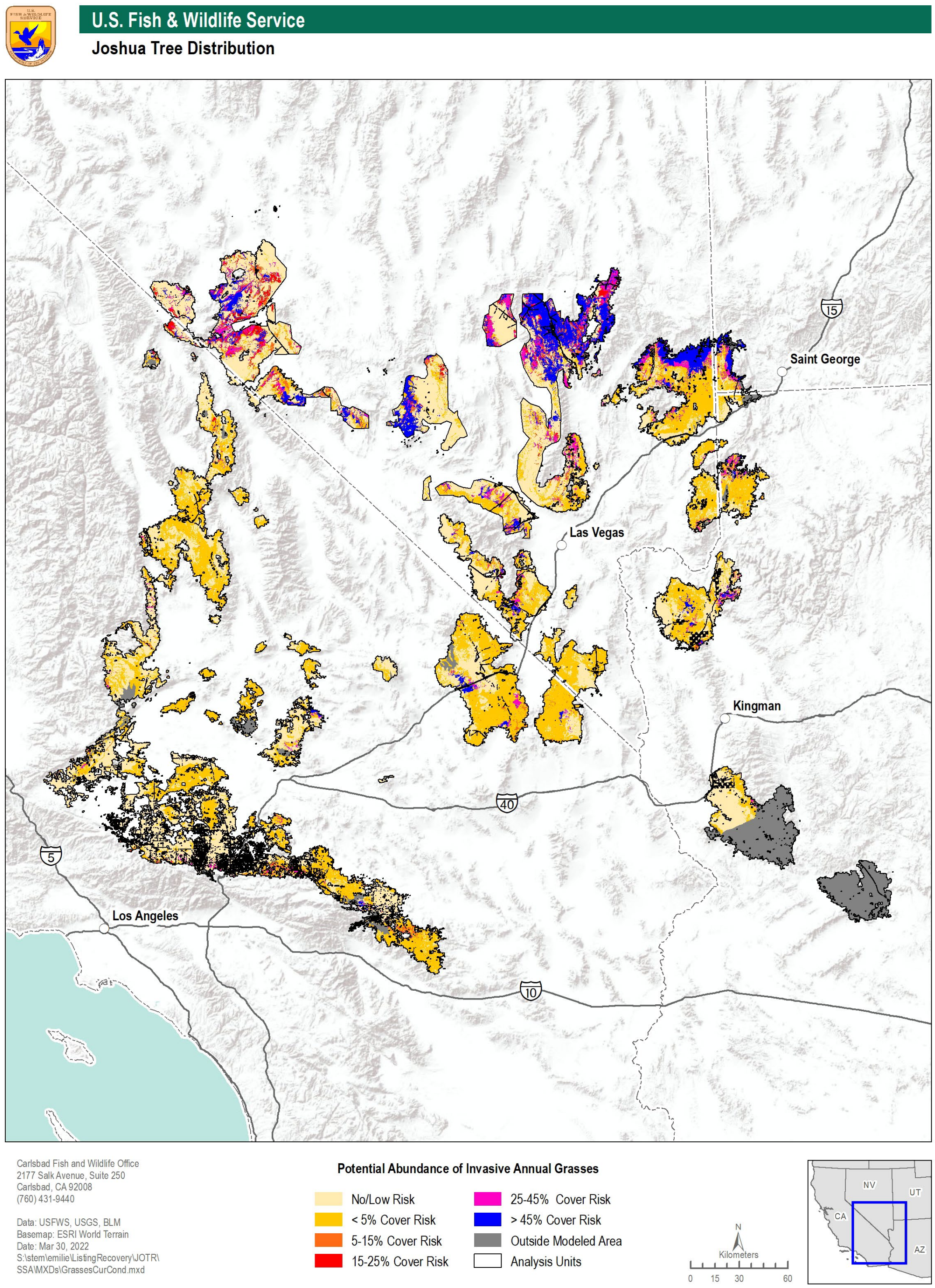

Figure 6-2. Modeled distribution of invasive grass cover (abundance) classes (Comer *et al.* 2013b, p. 10).

Survival post-fire depends on a complex interaction of fire severity, weather conditions, and herbivore pressure (DeFalco *et al*. 2010, entire; St. Clair *et al*. 2022, entire). Wildfires followed by extended periods of drought increase the probability of mortality even in mature Joshua trees. Drought is a source of additional stress due to the lack of moisture throughout the ecosystem. Following a wildfire, Joshua trees may be the predominant perennial plant species on the landscape. Herbivores have been recorded to exert extreme pressure on trees to access water and nutrients including removing the bark or hollowing out the inside of trucks, discussed in more detail under **section 6.5 Predation and Herbivory** below (Minnich 1995, p. 104; DeFalco *et al*. 2010, entire). Herbivore pressure can be particularly high on clonal growth that sprouts in response to fire (Minnich 1995, p. 104; St. Clair *et al*. 2022, p. 4). In a post-fire study at JTNP, both burned and unburned trees died over the course of the year study in part due to the exacerbating effects of drought (DeFalco *et al*. 2010, p. 246). Tree densities were substantially lower along the edge of a burn due to predation, including impacts to post-fire resprouts (23-fold lower; St. Clair *et al*. 2022, p. 4). High rainfall events can also impact post-fire survival. The loss of perennial shrub cover increases the potential for invasion by invasive grasses that more readily utilize available water, resulting in greater fuel continuity and an increase in the probability of wildfires.

Over recent decades the frequency of wildfires has increased in portions of the Mojave Desert, largely due to the proliferation of highly flammable invasive annual grasses, primarily *Bromus* sp. (cheatgrass and red brome) (Comer *et al*. 2013b, p. 7; Klinger *et al*. 2019, p. 17), that can proliferate in years of high precipitation such as during El Niño Southern Oscillations. The increased invasive grass cover, standing biomass, and litter contribute to higher fuel loads, more flashy fuels, and create continuity of fuel loads across the landscape (Brooks *et al*. 2013, p. 2). Under these conditions, wildfires tend to be large (tens of thousands of acres), high severity fires that can result in mortality of native plants. Between 1980 and 2004, wildfires have predominantly occurred in the middle elevation zone [3,937-5,905 ft (1,200-1,800 m)] (Brooks and Matchett 2006, p. 153; Klinger *et al*. 2021, p. 3), which largely defines the range of Joshua trees, and to a lesser degree lower elevation zones [less than 3,937 ft (1,200 m)]. Middle elevations have higher vegetative biomass than low elevation plant communities and invasive annual grass cover can be high, especially following years of above average precipitation, and has increased the intensity of fires within the region (Brooks and Matchett 2006, p. 158). Within JTNP, native grasses have been replaced in many areas by more flammable invasive annual grasses, which bridge gaps between woody plants. As a result, these invasive grasses tend to carry fires across larger areas (Brooks and Matchett 2006, p. 162). The resulting disturbance and reduced vegetative cover provide ideal circumstances for subsequent invasive grass proliferation. Wildfires can create a positive feedback loop encouraging recolonization and proliferation of invasive grass in burned areas and larger, more frequent fires that may result in type conversion to an invasive grass dominated plant community over time. More recent fires have measured in the thousands of acres in JTNP and are hypothesized to result in significant shifts in vegetation communities in the park within decades (Holmgren *et al*. 2009, p. 6).

The trend of increasing fire size and fire frequency has also been documented in the Mojave Desert. In the northeast range of *Yucca jaegeriana*, the Southern Nevada Complex fires—which were started by lightning during the summer of 2005—burned almost 740,000 ac (299,467 ha) 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). Similarly, large wildfires have been recorded in recent years in the central and western portion of the range of Joshua trees. In 2020, the Dome Fire burned 43,000 ac (17,401 ha) in the Mojave National Preserve and burned over a million Joshua trees (NPS 2022, unpaginated). The Dome Fire occurred at the height of the fire season in California and several other fires were burning throughout the state. As a result, additional fire-fighting resources were not available, and the fire burned for a longer period of time. Conflicts with allocating limited fire-fighting resources are anticipated to continue into the future.

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 (Esque *et al*. 2013, p. 2; McAuliffe 2016, p. 58). 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.

Post-fire habitat recovery and succession in desert plant communities require an extended period of time from decades to centuries, with the potential for the elimination of long-lived species with low reproductive output that are poor competitors (Minnich 1995, pp. 99, 103). The fire return interval (the time interval between two fires in the same location) across the majority of the range of Joshua trees is generally greater than 100 years with substantial areas greater than 300 years (Figure 6-3), though the longer-term intervals are supported primarily by expert opinion rather than carbon dating or other data sources (Sugihara *et al*. 2006, p. 66; Landfire 2022, unpaginated). Older plant communities tend to require longer periods to recover or may not return to the same state. Recovery time post-fire in desert plant communities was estimated at a maximum of 65 years to return to pre-disturbance cover, 72 years to achieve similar species diversity, and up to 582 years to achieve overall similarly (low of 19 years; Sorensen index) including studies that track recovery in the Mojave and Sonoran Deserts (Abella 2010, pp. 1257, 1260). Joshua trees' habitat are estimated to require approximately 100 years to reach densities, cover, and stature similar to pre-burn conditions, though nurse plant cover and the understory may attain pre-burn conditions in as little as a few years to several decades depending on whether the root crown survives (Minnich 1995, p. 104). Joshua tree recruitment is slow, and saplings are infrequent approximately 50 years post-fire (Minnich 1995, p. 103). There is also the possibility that rapid changes in the fire disturbance regime may exceed the ability of native species to adapt (Brooks and Matchett 2006, p. 149).

Several spatially explicit fire regimes have been characterized within the Mojave Desert that indicate the potential of imminent wildfires with both increasing probability of natural ignitions, frequency, and severity (Brooks and Matchett 2006, entire; Klinger *et al*. 2021, entire). Large, greater than 1,000 ac (405 ha) wildfires caused by natural ignition sources were modeled based on current conditions for topographic features, vegetation cover, invasive grass cover, and precipitation. Increases in the probability of ignition is estimated to increase at areas of high elevation, particular in the east, including many areas that have not burned for at least 50 years, and is driven by lightning, higher native vegetation cover, and invasive grass species (Klinger *et al*. 2021, p. 9). Fire frequency and the probability of ignitions are generally correlated; and fire frequency is estimated to increase in areas of monsoonal precipitation with increased lightning strikes, particularly at high elevation and in areas of high native vegetation and invasive grass cover. Increases in the frequency of fires is estimated at middle (5x) and high elevation (3x) areas relative to low elevation areas, with an increasing trend to the east (Klinger *et al*. 2021, p. 9). Higher burn severity is driven by vegetation and monsoon precipitation and occurs in the mountainous areas with severity increasing with both elevation and topography. Approximately 75 percent of Mojave Desert is characterized by low frequency and burn severity due to low vegetative cover in lower elevation areas. Both higher ignition probability and burn severity occurs to the north and in interior mountain ranges. As a result, a high frequency regime was modeled in the northeast and interior mountains, a high severity regime was modeled in the north and northwest, and a low frequency and low severity regime was identified in the south and west (Figure 6-4; Appendix C) (Klinger *et al*. 2021, p. 12).

The potential impacts to Joshua tree vary depending on the fire regime described above and whether that habitat is characterized by low [less than 4,000 ft (1,200 m)], middle [4,000–6,000 ft (1,200-1,800m)], or high [greater than 6,000 ft (1,800 m)] elevation plant communities (Table 6-1; Appendix D). Low elevations tend to have low severity fires due to low vegetative cover. Adult Joshua trees have a lower probability of dying from direct mortality and trees may avoid being burned due to their taller stature, though repeated low severity events contribute to increase charring over time that can increase the risk of mortality (DeFalco *et al*. 2010, p. 246). Low intensity wildfires at low elevation have the potential to support higher post-fire clonal resprouts (Minnich 1995, p. 103), compared to higher elevation vegetation communities that are characterized by higher burn severity. However, the risk and severity of wildfires may also increase following high rainfall events that promote invasive grass cover. Middle elevation blackbrush scrub vegetation communities are correlated with increasing fires, acres burned, and the invasive grass-wildfire cycle (Brooks and Matchett 2006, pp. 153, 155). Middle elevations typically have a higher fuel load, with sufficient vegetative cover to carry fires, and wildfires can therefore be more severe with increased invasive grass cover.

Moderate severity burns may result in adult mortality and is expected to char trees, including singeing the crown that may contribute to increased mortality and decreased tree densities over time, with the potential for post-fire resprouting. In moderate severity burns, above ground cover of nurse plants may be burned and clonal resprouting may occur where individual trees and their root system survive. We also project that the seedbank of Joshua trees and nurse plants may be negatively impacted. High elevation vegetation communities have heavier fuels and tend to have higher severity burns. High severity burns can result in direct tree mortality and may alter the subsequent vegetation composition and cover; however, there is limited Joshua tree occupied habitat modeled at high burn severity. A single high severity wildfire has been compared in effects to several lower severity fires in the same habitat), suggesting that fire return interval may not be the only measure of an altered fire regime. We project recruitment will be negatively affected by severity and frequency. The majority of trees in younger age classes, particularly less than 3.3 ft (1 m) are anticipated to be killed during a fire event (DeFalco *et al*. 2010, p. 246). The long-term potential effects on recruitment are tied to the frequency of wildfires and whether there is sufficient time for the associated vegetation community to recover. Post-fire clonal resprouts have a higher probability of surviving at higher elevations and latitudes with increased rainfall or snow melt, which minimize the potential for herbivore related mortality. All levels of fire severity may result in some patchiness across the burn area with areas where trees, nurse plants, and the seedbank may persist (Klinger 2022, pers. comm.). However, other researchers indicated that when a fire comes through an area it will likely burn all the available habitat (Esque 2022a, pers. comm.).

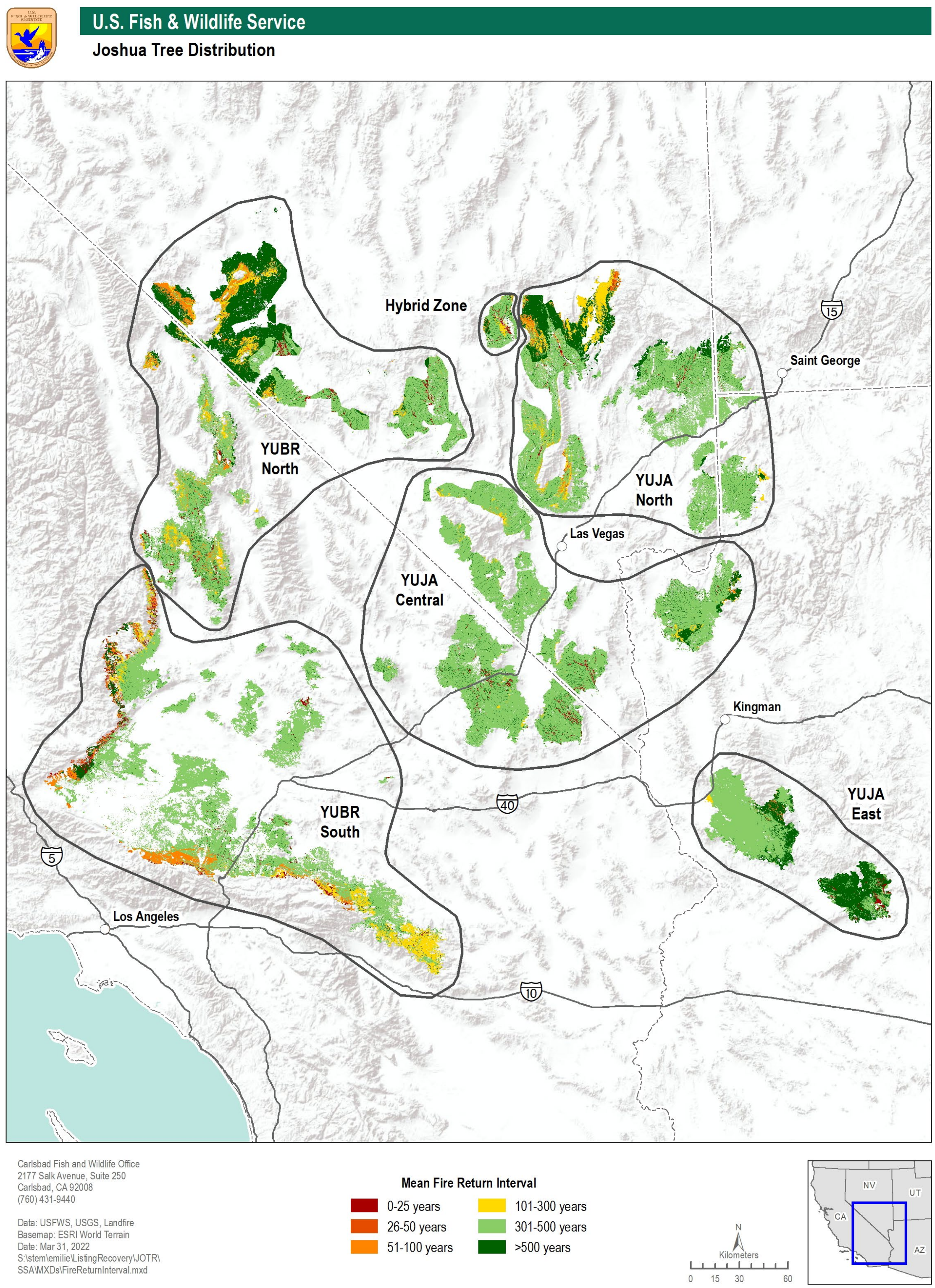

Figure 6-3. Fire return interval based on expert opinion and limited carbon dating data (LandFire 2022, unpaginated).

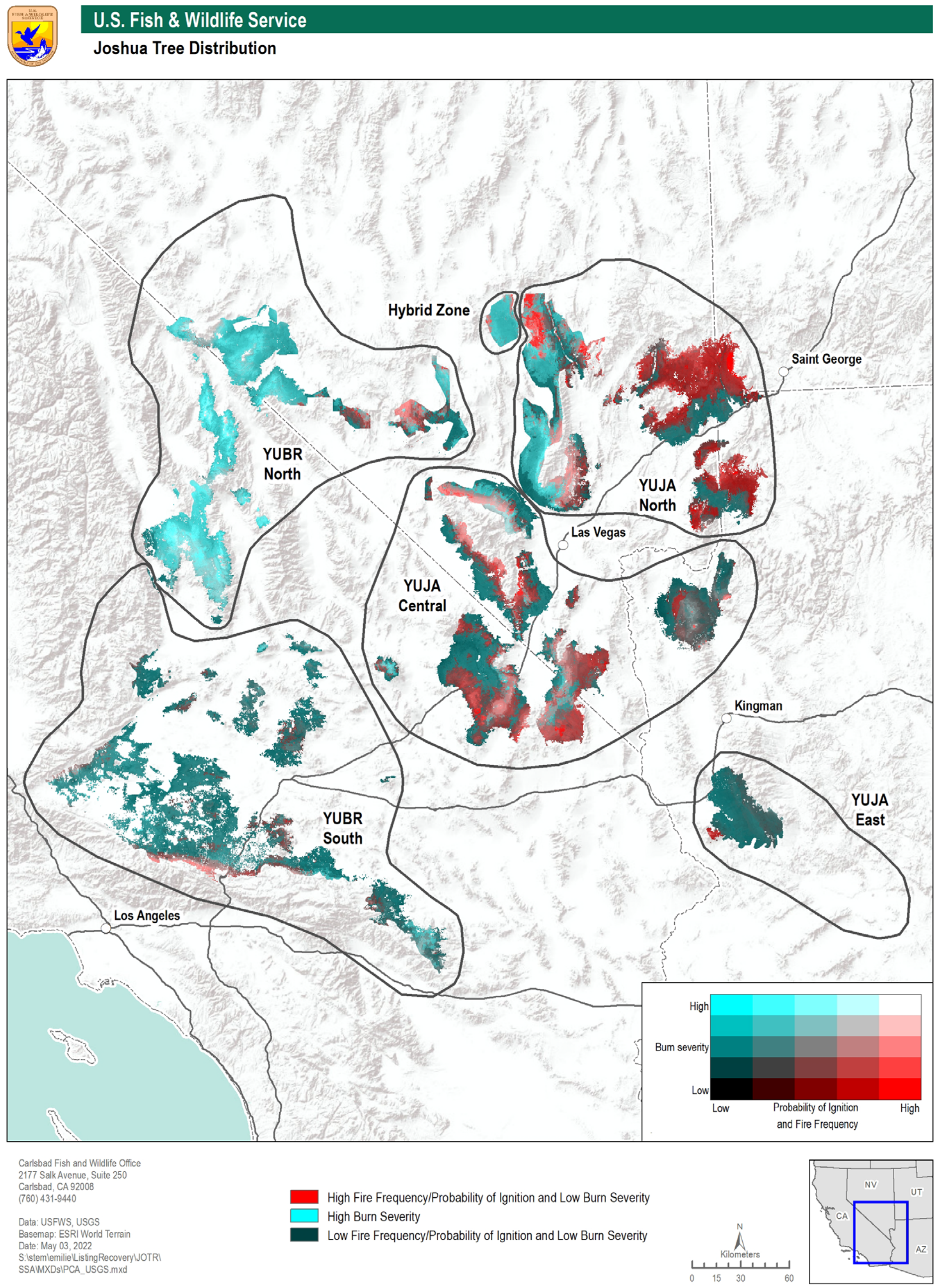

Figure 6-4. Wildfire regimes within the Mojave Desert.[2]

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[2] Based on modeled ignition probability, fire frequency and burn severity indicating areas of high frequency to the northeast and interior mountain ranges, high severity to the north and northwest and low frequency and low severity to the south and west. Limited areas of high severity and high frequency were modeled. The data presented are based on a principal component analysis (PCA) for probability of ignition and fire frequency (PCA 1) in red with darker colors indicating higher ignition probability and frequency. PCA 2 characterizes burn severity along a spectrum of blue-green with high severity indicated by light colors and low severity by a darker blue-green color.

Table 6-1. Summary of modeled fire regime with data presented for the proportion of the analysis unit impacted.[3]

Analysis Unit (AU)	Fire Frequency[1]	Ignition Probability[1]	Burn Severity[1]	Summary
YUBR North	**6**	**19**	**60**	High probability of infrequent, moderate to high severity wildfires across the majority of the AU that may lead to tree, seedling, and juvenile mortality. Small proportion with increased frequency. Imminent, uncommon, moderate magnitude threat.
YUBR South	**11**	**17**	**9**	Characterized by low frequency and low severity due to a high portion of the AU at lower elevations and lower vegetation cover. Natural ignition sources are low but human sources are projected to be high. Areas of high burn severity occur in the mountains and could result in tree mortality. On-going, uncommon, low magnitude threat.
YUJA North	**53**	**53**	**34**	High proportion of the AU subject to increased fire frequency and low burn severity because it has already burned multiple times and is projected to burn frequently in the future. Repeated charring is expected to lead to tree mortality and reduced tree densities. The frequency is anticipated to limit recruitment at lower elevations. Burn severity is forecasted to be high at higher elevations with increased frequency relative to AUs to the west which may lead to increase mortality and limited recruitment. On-going, frequent, moderate to high magnitude threat.
YUJA Central	**47**	**58**	**33**	Majority of the AU subject to increased fire frequency with low burn severity projected at lower elevations much of which has burned recently and is anticipated to result in some tree mortality and to limit opportunities for recruitment. Higher severity burns are projected at higher elevations and with sufficient frequency that tree mortality is anticipated. On-going, frequent, moderate to high magnitude threat.
YUJA East	**1**	**15**	**1**	A large proportion was not modeled but we project low severity fires due to low vegetation cover and limited ignition sources. Trees may be charred but the potential for tree mortality is low and there is likely sufficient time for habitat to recover such that recruitment is not limited by wildfire. Unlikely, uncommon, low magnitude threat.

[3] Fire frequency includes areas projected to have greater than one fire. Ignition probability indicates areas greater than 0.2. Burn severity indicates the proportion of the analysis unit with moderate and high severity.

Analysis Unit (AU)	Fire Frequency[1]	Ignition Probability[1]	Burn Severity[1]	Summary
Hybrid Zone	**15**	**9**	**90**	High probability of infrequent, moderate to high severity wildfires across the majority of the AU that may lead to tree, seedling, and juvenile mortality. Small proportion with increased frequency. Imminent, infrequent, moderate magnitude threat.

[1] Percent.

To assess the risk of wildfire, we evaluated the acres burned, and frequency of fires from 1878 to 2020 (NIFC 2022; unpaginated), the historical fire return interval over a 500-year period (Landfire 2022, unpaginated), and the estimated time for the vegetation community to recover. Our evaluation indicates that the majority of the Joshua tree's range currently experiences long fire-return intervals, generally greater than 300 and 500 years, though there is uncertainty regarding these estimates as described above. Fires have occurred in all the analysis units over the last 142 years, except the Hybrid Zone (despite having high fire risk in 32 percent of the analysis unit, based on the cover of invasive grasses), and only 226 ac (91 ha; <1 percent) burned in YUJA East (Table 6-2). We calculated the proportion of the Joshua tree's range that has not burned in 100 or more years and areas that burned in the last 100 years. Across all analysis units, shorter fire return intervals were observed on less than 10 percent of the area occupied by Joshua trees and was highest in YUBR South (9 percent; Figure 6-3). When we evaluated the size and frequency of fires over the last 100 years, the highest acreage and proportion of the population burned occurred in YUJA North (22 percent), followed by YUBR South (8 percent), and YUJA Central (5 percent). Between 78 and 100 percent of the acres burned only burned once; a small proportion (less than or equal to 2 percent of the analysis unit) of the same habitat burned multiple times in YUBR South, YUJA North, YUJA Central and YUBR North providing limited evidence for the potential for an altered regime (Cal Fire 2022, unpaginated; NIFC 2022, unpaginated).

Table 6-2. Summary of the fire frequency (times burned 1–6), total acres (hectares) burned and percent of the analysis unit burned from 1912 to 2020.

Location	1	2	3	4	5	6	Total	Proportion of the analysis unit (percent)
YUBR North	38,843 (15,693)	39 (16)					**38,882 (15,708)**	2
YUBR South	148,571 (60,023)	34,631 (13,991)	6,574 (2,656)	659 (266)	99 (40)		**190,533 (76,975)**	8
YUJA North	423,072 (170,921)	32,686 (13,205)	3,724 (1,504)	903 (365)	125 (51)	0	**460,510 (186,046)**	22
YUJA Central	98,910 (39,960)	4,457 (1,801)					**103,367 (41,760)**	5
YUJA East	226 (91)						**226 (91)**	0
Grand Total	**709,622 (286,687)**	**71,813 (29,012)**	**10,298 (4,160)**	**1,561 (631)**	**224 (90)**	**0**	**793,518 (320,581)**	**8**

Based on the wildfire history and modeled wildfire risk described above, the risk of increased wildfires is an imminent, low to moderate magnitude threat, though the acreage recently burned in the last 50 years (since 1960) is limited (9 percent on average) (Cal Fire 2022, unpaginated; NIFC 2022, unpaginated). The modeled risk of wildfires is based on current conditions and the modeled wildfire regimes are estimated to occur over the next 30 to 50 years (Klinger 2022, pers. comm.). The acreage projected to burn at the end of century could be as much as double the area that has burned in the last 50 years (9 percent on average, or up to 18 percent of the range) and wildfires are likely to occur in areas that have previously burned (Klinger 2022, pers. comm.). The analysis unit at highest risk is YUJA North based on the acreage of habitat recently burned; and both YUJA North and YUJA Central have a high proportion of the analysis units with estimated high ignition probability, fire frequency, and burn severity. YUBR North is at moderate risk for a moderate to high severity fire that could alter the vegetation composition and cover; the probability of natural ignition is lower in this analysis unit but there are population centers and high areas of visitation that are likely to increase human caused ignitions. YUBR South is considered at moderate risk; although 8 percent of the analysis unit has burned recently, most of the analysis unit is at low elevation with wildfire risk characterized by low frequency and severity. Ignition sources may be higher than projected in the models due to the high frequency of wildfires along the urban-wildland interface consistent with correlations between increasing human population density and fire ignitions (Keely and Fotheringham 2001, p. 1541). Disturbance and nitrogen deposition are also higher next to developed areas and continued disturbance will contribute to a higher proportion of invasive grasses in areas burned multiple times. Wildfire is a low magnitude threat in YUJA East because it is at low elevation and there is a low probability of natural ignitions.

Although we can describe areas of higher or lower fire frequency, we lack data on the potential timeframes between wildfire events and how that might vary geographically. The fire return interval is an additional factor that can have significant implications on the wildfire regimes and Joshua tree impacts described above. Shorter return intervals of can exacerbate impacts to Joshua trees and its habitat such that the vegetation does not have sufficient time to recover, while longer fire return intervals improve the chances of recovery (Klinger 2022, pers. comm.)

6.4 Climate Change

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). There is evidence that current summer temperatures (1991–2010) have increased by approximately 1° C relative to historical temperatures (1961–1990) (Figure 6-5; Wang *et al*. 2016, unpaginated). 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 (Archer and Predick 2008, pp. 23–24; Cook *et al*. 2015, entire; Jepson *et al*. 2016, p. 49). With respect to Joshua trees, we evaluated the potential effects of climate change related to increasing summer temperatures, increasing winter temperatures, variability in precipitation, drought metrics and the increased risk of wildfire. Climate data provided is based on data averaged across 13 General Circulation Models (GCMs) from the Climate Model

Intercomparison Project 6 (CMIP 6) (Mahony *et al*. 2022) compiled using the [ClimateNA tool] (version 7.21) (Wang *et al*. 2016, unpaginated). We conclude this section by discussing the available bioclimatic models for Joshua trees and the potential for the current distribution to be climatically favorable or unfavorable in the future, including the potential for range expansion. We did not thoroughly address these models in the 2018 Joshua tree SSA because the most recent model was limited to a relatively small portion of the Joshua trees' range and at the time we determined that the data could not be extrapolated to the entire range due to the lack of demographic data. Since our last review, additional bioclimatic models were evaluated that support the general conclusions of the earlier models that much of the range of both species will be climatically unfavorable and unlikely to support suitable climatic conditions due to increased temperatures, decreased precipitation, or a general increase in drought stress, though two studies also identified the potential for climate refugia in areas of habitat projected to be climatically favorable where all the species needs are forecasted to be met, in topographically diverse habitat. We evaluate the combined results of these models below (Table 6-3).

6.4.1 Increasing Summer Temperatures

Joshua trees do not generally occur in the hotter and dryer lower elevation areas of the Mojave Desert and it has been suggested that its distribution across the Mojave Desert may be constrained by summer maximum temperatures and winter minimum temperatures (Rowlands 1978, p. 179). The current distribution of *Yucca brevifolia* encompasses a summer temperature range of 69.4° to 87.3° F (20.8° to 30.7° C) and the range of *Y. jaegeriana* is similar but slightly warmer [72° to 91.9° F (22.2° to 33.3° C)] based on the mean temperature in the warmest month of the year. There is evidence that current summer temperatures (1991–2010) have increased by approximately 1° C relative to historical temperatures (1961–1990; Figure 6-5). Within the range of the Joshua trees and depending on the future scenario [RCP or Shared Socioeconomic Pathway (SSP) scenario] and analysis unit, climate models project between a 3° C (RCP 4.5; SSP 2) and 5° C (RCP 8.5; SSP 5) or greater increase in summer temperatures in the future (2071–2100) (Figure 6-4). Similar trends are observed for the extreme maximum temperature in the warmest month that is projected to exceed the extreme temperatures that Joshua trees have experienced in the recent past [98.1° to 118.4° F (36.7° to 48° C)], particularly under RCP 8.5 [107.6° to 127.8° F (42° to 53° C)]. The most dramatic increases are projected to occur in YUJA East which is warmer on average than the rest of the analysis units. Increasing temperatures will likely increase moisture stress on adults, potentially limit flowering at lower elevations, and may limit seedlings survival and establishment.

6.4.2 Increasing Winter Temperatures

Mean temperature of the coldest month is used as a surrogate for the minimum temperature a species can tolerate when exposed to cold and frost damage and often correlates with the northern distributional limit in tree species (Shafer *et al*. 2001, p. 202). A winter period of lower temperatures between 39.2° and 50° F (4° C and 10° C) improves seedling growth and survival in Joshua trees. Cold season conditions across the range of Joshua trees were characterized based on the mean temperature of the coldest month (MCMT; typically January). Future cold season temperatures ranged from 30.7° to 48.0° F (-0.7° to 8.9° C) for *Yucca brevifolia* and between 34.3° to 51.4° F (1.3° and 10.8° C) on average for *Y. jaegeriana*.

Although both species of Joshua trees have experienced extreme climate conditions as described above, we lack information on whether vigor or survival would be reduced over a sustained period at either projected temperature extreme. Currently all analysis units are exposed to a winter period of cold temperatures and YUBR North and the Hybrid zone experience colder temperatures on average compared to the other populations. Future winter temperatures are projected to increase by similar a magnitude as summer temperatures under each scenario. YUJA East is near the upper threshold (see **section 5.1.5 Cold Season Period** above) for cold season temperatures under current conditions and is projected to be warmer than 50° F (10° C) under both RCP 4.5 and RCP 8.5, as a result seedling growth and establishment is anticipated to be reduced. (Figure 6-5).

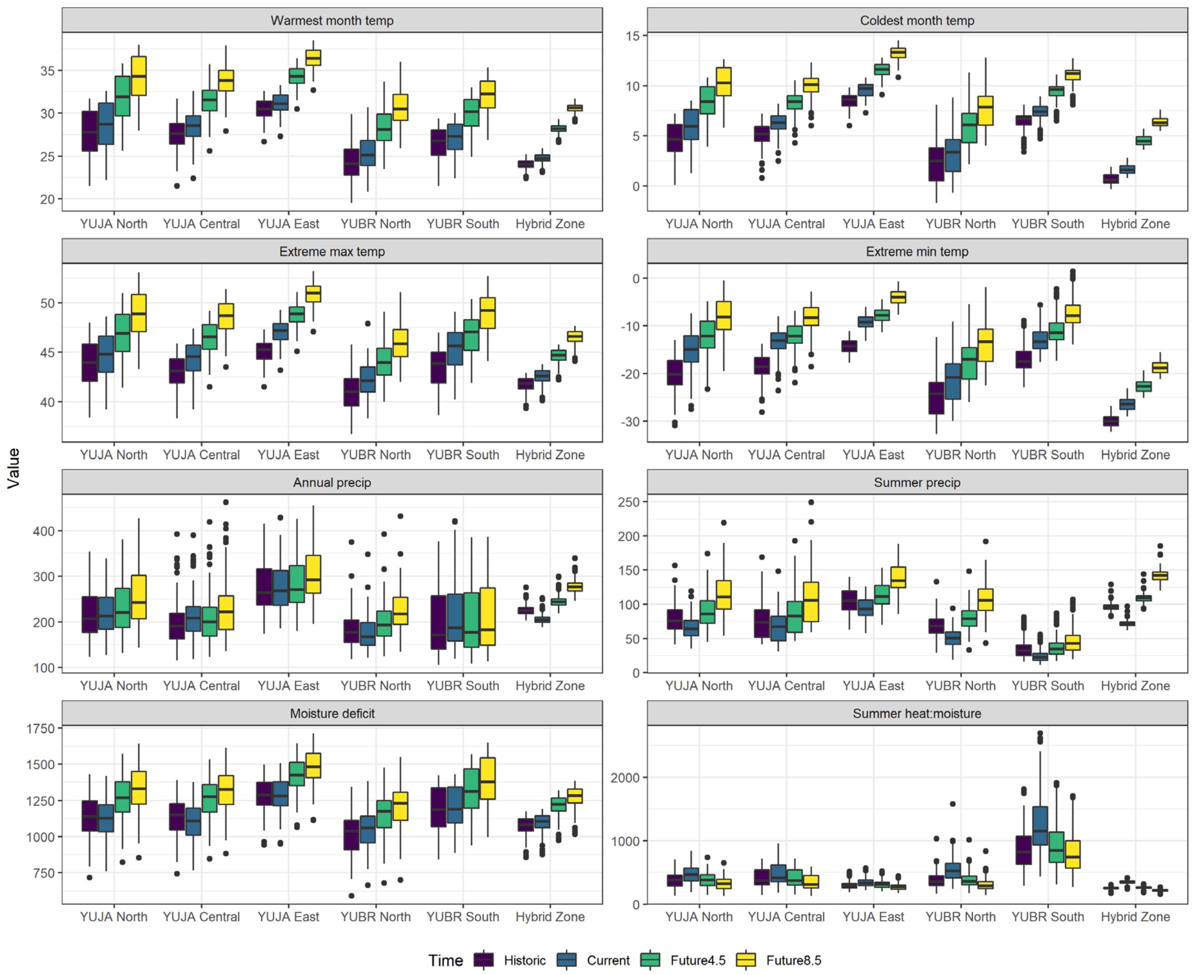

Figure 6-5. Summary of climatic parameters by analysis unit based on a random sample of 100 points within each analysis unit.[4]

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[4] The range of values illustrated in the boxplots is based on the variability within the analysis unit and not the variability in temperatures during the period indicated. Climate parameters include mean temperature (°C) of the warmest month, mean temperature (°C) of the coldest month, extreme minimum temperature (°C) over 30 years, extreme maximum temperature (°C) over 30 years, mean annual precipitation (mm), mean summer precipitation (mm), summer heat-moisture index (higher values indicate hotter, drier years), and Hargreaves climatic moisture

6.4.3 Drought

Low rainfall and drought are aspects of desert ecology. Joshua trees have evolved in a desert climate and have adaptations to arid conditions such as a thickened cuticle and strong stomatal regulation under conditions of drought stress (Smith *et al*. 1983, p. 13). Historically droughts have occurred throughout the range of Joshua tree though the magnitude, in terms of the rainfall deficit relative to average conditions, and the duration of the drought varies (Appendix E). Droughts typically last for 1 to 3 years; and average or higher rainfall is typically recorded in the intervening period (1 to 3 years). Extended drought periods of 4 to 7 years have occurred since 1960s but are infrequent. The largest magnitude droughts have occurred in the last 30 years; and at lower elevations and latitudes both the magnitude and duration of drought periods are longer on average. Despite adaptations to desert conditions, drought and warming temperatures contribute to decreased survival for immature stages, but the effect of drought on adult trees is less clear and likely depends on the length of the drought and site conditions.

There is uncertainty in the projected quantity of future precipitation in the desert southwest based on variability in the climate models, but models forecast that the amount of average annual rainfall is not projected to vary substantially. However, there is general agreement that precipitation is forecasted to be more extreme. Climate models forecast an increase in the variability of future precipitation including the potential of high precipitation events generally tied to El Niño oscillation and the potential increase of prolonged drought conditions in the intervening period. Although range-wide monitoring data is lacking, there is recent evidence of drought related mortality particularly of immature age classes. 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 increases in individual mortality (Cornett 2020, p. 8). Tree mortality has been observed in the recent past due to extended drought conditions, separate from impacts associated with wildfire (Esque *et al*. 2010, p. 10; Cole *et al*. 2011, p. 139). In a recent study a total of 94,635 ac (38,314 ha) of Joshua tree occupied habitat was lost and individuals within the habitat are presumed to have died as a result of drought within the last 20 to 40 years (Esque 2022a, pers. comm.). Similarly, in a non-replicated study at a high elevation site in Cima Dome in the Mojave National Preserve, approximately 23 percent of juvenile *Yucca jaegeriana* trees died due to the effects of drought and drought-exacerbated herbivory (Cornett 2018, pp. 86–87). The study included a 6-year period of drought and 6.5 percent decline in the population.

To evaluate potential changes in future precipitation and drought conditions we evaluated four parameters: annual precipitation, summer precipitation, Hargreaves's climatic moisture deficit

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deficit index (mm; higher values indicate increasing drought stress). The historic period is from 1961–1990, current period is 1991–2020, future period is 2071–2100 and includes two representative concentration pathways scenarios (SSP 2–4.5 and SSP 5–8.5). Projected temperature and precipitation data was averaged across 13 General Circulation Models (GCMs) from the Climate Model Intercomparison Project 6 (CMIP 6) (Mahony *et al*. 2022, entire) compiled using the ClimateNA tool (version 7.21) (Wang *et al*. 2016, unpaginated).

index, and the summer heat moisture index from 13 GCMs from CMIP 6 utilizing the ClimateNA tool (Figure 6-7) (Wang *et al*. 2016, unpaginated). The latter two climatic parameters consider the combined effects of temperature and precipitation. Hargreaves's climatic moisture index is a measure of drought stress and summer heat moisture index provides an assessment of moisture conditions during the seedling establishment period. Future annual precipitation is similar to current conditions, though there is some evidence that annual precipitation will be higher in YUBR North and the Hybrid zone, particularly under RCP 8.5. Summer precipitation is projected to increase relative to the current period that has been characterized by extended droughts and substantially higher summer precipitation is projected under RCP 8.5, though there is a high degree of uncertainty in modeled future precipitation including monsoonal rainfall. YUBR South is currently experiencing high moisture stress during the recruitment period that correlates with current observations of reduced recruitment, particularly along the southern limit. We project lower recruitment to occur in drier areas; however, this does not provide strong evidence that the species will not persist in drier areas. The time period necessary to evaluate successful recruitment and species persistence should be consistent with the generation time of the species which is 50 to 70 years. Regardless of potential increases in precipitation, the future moisture deficit is anticipated to increase compared to current conditions due to the magnitude of forecasted temperatures (Figure 6-5). Although some models are projecting periodic, increased rain events, overall the pattern of increasing drought stress is likely to occur across all analysis units and is anticipated to reduce vigor, growth, recruitment, and survival and increase herbivory and predation, discussed further below.

6.4.4 Future Habitat Suitability

Climate refugia are believed to be important for species survival in the face of climate change (Lenz 2001, p. 72). Several studies have projected the potential effects of future climate change on the distribution of Joshua trees by modeling the relationship between the species' current distribution and climatic parameters (Shafer *et al*. 2001, entire; Dole *et al*. 2003, entire; Cole *et al*. 2011, entire; Barrows and Murphy-Mariscal 2012, entire; Thomas *et al*. 2012, entire; Comer *et al*. 2013b, entire; Sweet *et al*. 2019 , entire). These studies use statistical models, the species' baseline distribution data, and climate parameters to develop a climate model that provides a good fit for the species' current distribution. These models are then applied to a future period under a range of climate scenarios and GCMs to identify habitat areas projected to be climatically favorable in the future where all the species needs are projected to be met (e.g., sufficient pollinators, survival, and appropriate recruitment conditions to maintain population abundance), based on having the same climate conditions as the species' current distribution. The bioclimatic models also identify areas modeled to be climatically unfavorable that are unlikely to support suitable climatic conditions based on the habitat that Joshua tree currently occupies either due to increased temperatures, decreased precipitation, or a general increase in drought stress. We project that these areas may have a reduced ability to support species needs due to decreased habitat quality with the potential for reduced growth, lower recruitment, increased predation, tree mortality, decreased tree densities, and loss of occupied habitat, though there is uncertainty in the timing and magnitude of the species response. Over time these models for Joshua trees have been refined with improved, local scale distribution and habitat data, downscaled climate data, and field validation of the model that have identified potential climate refugia not identified in the coarser scale models (Barrows and Murphy-Mariscal 2012, entire; Sweet *et al*. 2019, entire), albeit for a limited portion of the species' range (YUBR

South; JTNP). Table 6-2 provides a summary of the models considered in this analysis and the projected future bioclimatic distribution of Joshua trees.

The modeled areas of climatically favorable habitat from these studies have been likened to a species' climate tolerance, climate envelope or potential niche (Shafer *et al*. 2001, p. 207; Cole *et al*. 2011, p. 139). The models do not project the potential realized niche (future species' distribution; Thomas 2022a, pers. comm.) due to uncertainties in the species' biological response. For example, the loss of climatically favorable habitat does not indicate immediate death or loss of occupied habitat in those areas, but identifies where the species' current climate requirements may not be met in the future (Shafer *et al*. 2001, p. 207). The approach is primarily based on projections of future climate data (RCPs), with its own inherent uncertainty (Knutti and Sedláček 2013, p. 370), to project the potential future climatic pressures and constraints on Joshua trees. Depending on the RCP and timeframe modeled, temperature projections can vary from one to several degrees Celsius increasing the uncertainty the further into the future we project. Future projections of habitat suitability also do not address other factors and processes that also contribute to determining a species' distribution such as the species' tolerance to climate parameters, singly and in combination, as well as interspecific interactions, such as pollination and seed dispersal, that also affect recruitment of both species.

The bioclimatic models that evaluated the range of both *Yucca brevifolia* and *Y. jaegeriana* have projected large-scale reductions in the availability of climatically favorable conditions in the future, particularly in the southern portion of the range for both Joshua tree species (Shafer *et al*. 2001, p. 210; Dole *et al*. 2003, p. 142; Cole *et al*. 2011, p. 143; Thomas *et al*. 2012, pp. 14–16; Comer *et al*. 2013b, pp. 142–144). Although the studies used different modeling methods, input datasets, and coarser scale climate data, there is general agreement that as much as 80 to 100 percent of the species' current distribution is projected to be climatically unfavorable at the end of the century. We project that these areas may have a reduced habitat quality and the ability to support species needs (e.g., sufficient pollinators, survival, and appropriate recruitment conditions to maintain population abundance), with the potential for reduced growth, lower recruitment, increased predation, tree mortality, decreased tree densities and loss of occupied habitat, though there is uncertainty in the timing and magnitude of the species response, as discussed in our projections for future conditions discussed in **section 6.4.7 Climate Change Summary** and **section 8.1 Future Scenario Considerations**. Changes in the species' future distribution are largely attributed to increases in both cold and warm season temperatures that are anticipated to increase aridity and moisture stress. Although there is variability in modeled future precipitation, the forecast for potential wide-spread loss of climatically favorable habitat remains. Increasing cold season temperatures are also anticipated to restrict the portion of the species' range that will be suitable for recruitment due to the relationship between seasonal cold period [39.2° and 50° F (4° and 10° C)] and increased seedling growth and survival, though we lack information on the duration of the cold period required to achieve this effect (Went 1957, p. 173). The largest potential loss of climatically favorable habitat occurs if future CO_2 emissions are unmitigated (e.g., RCP 8.5). These studies also identify potential climatically favorable habitat outside of the species' current distribution that may allow for range shifts and habitat expansion at higher elevations and northern latitudes.

More recent studies using downscaled climate, habitat, and recruitment data (Barrows and Murphy-Mariscal 2012, entire; Sweet *et al*. 2019, entire) have highlighted the potential for small areas of climatic refugia within the southern range of Joshua tree (*Yucca brevifolia*) in areas of complex topography, such as steep north facing slopes and higher elevations that were projected to be climatically unfavorable in the earlier, coarser scale models. Barrows and Murphy-Mariscal (2012, p. 33) projected that between 22 to 34 percent of the species' current distribution in JTNP (YUBR South) would continue to be suitable under a future increase of 3.6° F (2° C) and 2 to 10 percent of the current distribution was projected to be suitable and provide climatic refugia under a 5.4° F (3° C) increase (Table 6-2; Barrows and Murphy-Mariscal 2012, p. 33). A subsequent study by Sweet *et al*. (2019, p. 7) in JTNP projected climate refugia in 18.6 percent of the current distribution based on a 5.34°F (2.98° C; RCP 4.5) increase in the warmest quarter of the year. Only 0.02 percent of the habitat was modeled to be climatically suitable based on a 9° F (5.0° C) increase (RCP 8.5; Sweet *et al*. 2019, p. 7). The authors also noted that approximately half of the climate refugia under RCP 4.5 overlap with the historical fire footprint (Sweet *et al*. 2019, p. 7), indicating that modeled refugia may not be functional refugia if these areas experience increased risk and frequency of wildfire that can no longer support the species, discussed further below. Both studies validated their models through a field assessment of tree densities and evidence of recruitment. Importantly, both studies found evidence that suitable habitat for recruitment may have already shifted, with juveniles mainly occurring within a smaller subset of the current adult distribution similar to the areas projected to be suitable in the future (Barrows and Murphy-Mariscal 2012, p. 34; Sweet *et al*. 2019, pp. 9–11). But both studies noted that they were unable to adequately model small-scale hydrologic refugia that are thought to be important to both Joshua tree species, due to the scale of the available climate data (Barrows and Murphy-Mariscal 2012, p. 33; Sweet *et al*. 2019, p. 7, 12). These local-scale studies are limited to the vicinity of JTNP and it is therefore not appropriate to quantitatively extrapolate these results across the species' range. However, it is likely that similar climate refugia exist within the topographical complexity of the mountainous southwestern United States where Joshua trees occur and were missed in earlier studies that used a coarser scale of climate and habitat data.

These studies help inform our understanding of the potential for Joshua trees to shift in space or remain in place in response to climate change, particularly when physiological based models are not available (Thurman *et al*. 2020, entire). Several range-wide studies have projected the potential for range expansions in future suitable climatic habitat outside of the species' current range (Shafer *et al*. 2001, entire; Dole *et al*. 2003, entire; Cole *et al*. 2011, entire; Thomas *et al*. 2012, entire; Comer *et al*. 2013b, entire). Results from Cole *et al*. (2011) showed potential habitat expansion within Joshua trees' historical range by maintaining the current elevation limit that has not changed substantially since the Holocene (Cole *et al*. 2011, p. 141). In contrast, Dole *et al*. (2003) allowed the species' elevation range to increase based on an increased tolerance to low temperature extremes associated with a doubling in CO_2 concentration (Dole *et al*. 2003, entire). Increased habitat suitability is projected to occur at higher latitudes and elevations both within and outside the species' current range. It is less clear whether Joshua trees will be able to utilize this new potential habitat and that will depend on the availability of suitable substrate, dispersal capabilities, migration rates, the frequency of disturbance, and the response of the species that already occupy that space (Lenz 2001, p. 72; Shafer *et al*. 2001, p. 207). Joshua trees are generally associated with alluvial fans and bajadas at the base of mountains, and it is not clear if Joshua trees will readily colonize and establish viable populations on steeper, rockier habitat that currently exists at higher elevations. Dispersal distances are informed in part by prehistoric data, though we acknowledge the lack of precision in these estimates because the density of trees within Joshua trees prehistoric distribution is unknown and the velocity of current climate change may be faster in the modern era. Based on Pleistocene packrat middens, Joshua trees' migration during the Holocene is estimated to be approximately 6.5 ft/yr (2 m/yr) (Cole *et al*. 2011, p. 141). Although some areas of future climate suitability may be contiguous with the species' current range, the current distribution is patchy and includes large areas of unoccupied habitat. The relative isolation of currently occupied patches from future suitable habitat will limit the ability of the Joshua trees to take advantage of future potential habitat suitability. Habitat fragmentation from development and wildfire have the potential to hinder the future dispersal potential of Joshua trees. Ultimately dispersal and successful establishment in new habitats will be driven by biotic interactions particularly seed dispersal, pollination, vegetative competition, and the species' tolerance to novel habitat conditions (e.g., soils), within the context of future climatic conditions.

These bioclimatic models are predicated on several important assumptions. A thorough understanding of the species' range, including accurate knowledge of Joshua trees presence and absence, provides the baseline for species distribution modeling (Sofaer *et al*. 2019, p. 546), though not all models require absence data. In the case of Joshua trees, we continue to receive new information refining the species' range because Joshua trees are wide-ranging and all areas of its range had not been adequately surveyed until recently (WEST Inc. 2021; Esque 2022b, pers. comm.). As a result, some additional occurrences and suitable habitat areas do not appear to be included in the earlier models, which may increase uncertainty in the modeled results (Appendix G). Table 6-3 summarizes the models where we have spatial or georeferenced data to compare the fit of the models to the current distribution. The models are based on the well-established global relationship between climate and the distribution of vegetation communities. They assume that the current species' range is in equilibrium with the baseline climate period used in the analysis (Cole *et al*. 2011, p. 145) and that the climate parameters modeled are the main factors driving the species' distribution (Shafer *et al*. 2001, p. 202; Dole *et al*. 2003, p. 143), though there is evidence of recent warming trends over the last 40 to 50 years that Joshua trees may not be equilibrated to (Figure 6-5). The spatial scale of the Joshua tree data is also assumed to be appropriate; but these studies are limited by the scale of the available climate models and have evolved overtime from 2.5 mile (mi) [4-kilometer (km)] and 1.6 mi (1 km) datasets to more recent downscaled models with 885-ft (270-m) resolution (Sweet *et al*. 2019, p. 5). Lastly, physiological effects of increasing CO_2 concentration are considered to have minor effects on these models; with the exception of Dole (2003, p. 141), which showed a slightly higher amount of current distribution remaining occupied due to increased freezing tolerance. Increasing CO_2 may improve the tolerance of Joshua trees to freezing temperatures based on laboratory studies (Loik *et al*. 2000, p. 51). This result suggests that seedlings may have a higher likelihood of surviving cold temperatures under elevated CO_2, potentially allowing habitat expansion to higher elevations and northerly latitudes, though it is not clear how seeding will perform in natural conditions (Loik *et al*. 2000, p. 51). One study that specifically examined these effects on habitat suitability indicated slightly more of the current distribution would remain occupied in the future when freezing tolerance was included (Dole *et al*. 2003, p. 142).

6.4.5 Increased Risk of Wildfire

Future climate models project hotter and drier conditions with more extreme precipitation patterns in the desert southwest including extended periods of high rainfall and prolonged periods of drought that are projected to increase the risk of wildfire. Precipitation affects fire regime through impacts on vegetation growth including invasive grasses (Tagestad *et al*. 2016, p. 389). High winter precipitation associated with El Niño cycles promote high native and invasive grass cover that creates fuel continuity between shrubs and increases the probability that wildfire will be sustained and spread. Summer storms are associated with high winds and lightning, a source of ignitions (Klinger *et al*. 2021, p. 13), though high winds may not be required for a wildfire to spread when nonnative grasses are present (Minnich 1995, p. 101). Wildfires are projected to increase in number, size, and frequency in the future (Tagestad *et al*. 2016, pp. 389, 396). Periods of drought may reduce the probability of wildfire at low elevations with low vegetative cover and shift the distribution of woody plant species at higher elevations (Tagestad *et al*. 2016, p. 394). Increased CO_2 concentrations are also projected to increase invasive grass cover.

Although future wildfire conditions have not been modeled, we made preliminary projections based on established wildfire regimes in the Mojave Desert (Klinger *et al*. 2021, entire) and the effects of precipitation on vegetation at low, middle and high elevation plant communities (Brooks and Matchett 2006, entire; Tagestad *et al*. 2016, entire). Low elevation plant communities, particularly at lower latitude, are projected to have reduced vegetative cover and higher mortality of woody plant species, such as Joshua trees, with prolonged droughts reducing fuel loads. Infrequent periods of high precipitation are anticipated to favor the spread of invasive grass species. These pulses of higher vegetative cover may temporarily increase the risk of wildfire at low elevations. Overall, the fire frequency and intensity are projected to remain low in the south and southeast range of Joshua trees and increased frequency of wildfire is projected to continue to the northeast (Klinger *et al*. 2021, entire). Areas of low vegetation cover and higher fire frequency are expected to have reduced vegetative cover and fuel loads in the future and are likely to be dominated by invasive grasses.

Projections for middle elevation vegetation communities are less clear in the future because this area has already experienced an increase in wildfires over the last 40 to 50 years. It is likely that the invasive grass-wildfire cycle will expand throughout this zone resulting in the degradation and potential loss of suitable Joshua tree habitat associated with prolonged droughts and increased fire frequency. *Erodium* spp. cover is particularly pronounced post-fire and has the potential to alter post-fire recovery in middle elevation habitat (Tagestad *et al*. 2016, pp. 2, 11). Joshua trees are expected to persist on the landscape in areas of moderate burn severity. In middle and high elevation plant communities, increased temperatures are projected to lead to increased aridity and the potential for mortality of wood trees and shrubs that create increased fuel loads and increase the probability of high severity burns which corresponds with areas of modeled climate refugia. For example, the recent 2020 Cima Dome fire occurred in an area projected to serve as future climate refugia (Smith *et al*. In Review, p. 48) and approximately 10 percent of projected climate refugia has burned. High severity wildfires increase the probability of Joshua tree mortality and the conversion of woody vegetation to herbaceous cover dominated by invasive grasses. Although the probability of ignition could vary with changes in monsoonal storm patterns and population densities, wildfires at high elevation are projected to initially be of high severity. Subsequent to these events we project that burned areas have a high probability of being colonized by invasive grasses, particularly Bromus tectorum cheat grass in the north and northeast, and the elevation limit of its distribution may increase with increasing temperatures and the potential for increased fire frequency. We forecast vegetation cover to decrease overtime with extended droughts and increased fire frequency, particularly to the east and northeast. Similar to current conditions, future projections are hampered by a lack of data on the fire return intervals in the future. Overall, we project there to be a high probability of large, uncommon, catastrophic wildfires at middle and high elevations in areas that have not burned, and lower potential and frequency of wildfires at low elevations. Patches of unburned habitat and individual Joshua trees may remain within burned areas at middle and high elevation zones due to topographic heterogeneity and hydrological refugia. We project that approximately 12 to 18 percent of occupied habitat may burn by the end of the century, roughly double the percent of habitat that has burned in recent years, and areas that have burned are more likely to burn again.

6.4.6 Potential Climate Impacts on the Yucca Moth and Rodent Seed Dispersers

The potential effects of increasing temperatures, drought, and increasing risk of wildfires on Joshua trees' habitat are complex and are dependent on the direct effects of future climatic conditions described above, as well as, the strength and magnitude of the interaction with their specialist pollinators and rodent seed dispersers. There is current evidence of a shift toward an earlier flower period and the potential for asynchronous shifts in phenology that may negatively affect reproductive output. In the southern portion of the distribution of *Yucca brevifolia*, Joshua trees are flowering earlier (Cornett 2019, p. 124; Harrower 2022b, pers. comm.). Flowering has been recorded as early as November increasing the risk of exposure to frost and freezing temperatures, though no to limited seed production occurred. Although we do not have information on whether yucca moth emergence is shifting earlier, there is site-specific evidence that low elevation habitat in the region may no longer be supporting yucca moths and sexual reproduction (Harrower and Gilbert 2018, p. 11). Overall, the potential effects of climate change on the yucca moth are unknown, including whether individuals have the potential to survive low to moderate intensity wildfires. We project that drought and drought-exacerbated seed predation and herbivory will increase in the future with a high likelihood of a reduced seed crop and corresponding negative effects on recruitment, similar to patterns observed during current periods of drought (Borchert and DeFalco 2016, p. 833), but with the potential for higher magnitude effects. Prolonged droughts may have the potential to reduce rodent populations due to limited availability of water and food resources, though we have no future climate projections for the suite of rodents that forage on Joshua trees, nor the rodent abundance required to assure sufficient level of seed dispersal. If conditions continue to be drier in the future and result in greater seed predation or a lower number of viable seeds, both Joshua trees and the yucca moth pollinators could be vulnerable (Harrower and Gilbert 2018, p. 2). However, with the temperature increases experienced to date and prolonged drought conditions several mast flowering events were still recorded in the last decade, even at the southern limit of their distribution, and masting events are known to satiate rodent populations (Borchert and DeFalco 2016, pp. 831, 835).

6.4.7 Climate Change Summary

The distribution of Joshua trees is presumed to be limited by cold winter temperatures in the north and high summer temperatures in the south, and precipitation is believed to drive its eastern and western limits (Cole *et al*. 2011, p. 143). The contraction of the species' Pleistocene range in response to the approximate 7.2° F (4° C) warming in the early Holocene has been used to demonstrate Joshua trees intolerance to warming temperatures and the potential for future range contractions under projected climate change (Cole *et al*. 2011, pp. 138, 145). The potential effects of climate change are being observed near the southern limit of *Yucca brevifolia* in

California (Cornett 2019, entire; Sweet *et al*. 2019, entire; Graver 2022, entire; Thomas 2022b, pers. comm.). Research suggests that recent increases in temperatures and drought conditions are influencing recruitment patterns in JTNP (Barrows and Murphy-Mariscal 2012, p. 34; Sweet *et al*. 2019, pp. 9–11). Similarly, a 46 percent reduction in tree numbers and the percentage of young trees was recorded at Red Rock Canyon State Park over a 21-year period characterized by increased temperatures and reduced precipitation (Cornett 2020, p. 109). There is not the same level of information currently available for the rest of the distribution, but scientists indicate that these results are indicative of the future species response due to climate change. Additionally, information on status is forthcoming; USGS is currently revisiting sites within the National Park system that were first surveyed in 2007 to 2010 and the results are expected between 2023 and 2024, though data range-wide is still lacking.

Although climatic habitat suitability models tend to oversimplify the physiological, ecological, and genetic process that will determine the potential distribution of Joshua trees under future climate change, they are the best available information on how climate change may affect Joshua trees' distribution in the future. Under a lower emission scenario approximating RCP 4.5, 66 to 80 percent of Joshua trees' distribution is projected to be climatically unfavorable at the end of the century, and 20 to 44 percent of the range is anticipated to provide climatically favorable conditions in climate refugia where all the species needs (e.g., sufficient pollinators, survival, and appropriate recruitment conditions to maintain population abundance) are projected to be met. Under a high emission scenario approximating RCP 8.5 at the end of the century, approximately 90 to 99 percent is projected to be climatically unfavorable, with 1 to 10 percent of the distribution potentially providing climate refugia (Table 6-3). There is a high degree of uncertainty in the species' response to climatically unfavorable conditions at the end of century, based on both the magnitude of the potential effects of the temperature increases forecasted, and the timeframe over which individuals will be exposed to climatically unfavorable conditions. We acknowledge that Joshua trees may experience reduced flowering, growth, and recruitment, and increased mortality and risk of predation, including the potential for loss of occupied habitat and range contractions under unfavorable climatic conditions. But there is more uncertainty the further into the future we project; therefore, the timing and magnitude of these responses are difficult to forecast at this time. It is not clear how and when Joshua tree individuals or populations may begin to respond to the effects of climatically unfavorable conditions, including when recruitment may be reduced, how long adult trees may persist in climatically unfavorable conditions, and if there are physiological thresholds (Shafer *et al*. 2001, p. 207; Thomas 2022a, pers. comm.). Furthermore, the rate of warming and maximum exposure temperatures varies depending on the RCP evaluated, contributing to further uncertainty the further into the future we project potential species effects (Knutti and Sedláček 2013, p. 370). Based on the model results and in consideration of the uncertainties, the potential exists for the loss of occupied habitat and range contractions at lower elevations and latitudes along the southern limit of *Yucca brevifolia* and *Y. jaegeriana* at the end of the century, with a potential for climate refugia at higher elevation, though the extent of occupied habitat loss is unclear. Forecasted climate refugia has the potential to overlap with middle and high elevation vegetation zones projected to have an increased risk of wildfires, though there is uncertainty in where future wildfires may occur (Klinger 2022, pers. comm.). The potential for habitat expansion beyond the current distribution is greatest to the north and east, and in areas that would likely require assisted migration for Joshua trees to colonize in the future (Cole *et al*. 2011, p. 146). There are discrepancies between the modeled distributions in the climate models and our understanding of

Joshua trees' current distribution based on the empirical study conducted by USGS (Appendix F; Esque 2022a, pers. comm.), which contributes uncertainty in our estimates of future habitat suitability and the species' distribution (Sofaer 2019, p. 546). In addition, coarse scale climate modeling may not adequate capture microclimates (Nadeau *et al*. 2022, p. 3230) and small-scale hydrologic refugia (Barrows and Murphy-Mariscal 2012, p. 33; Sweet *et al*. 2019, p. 7,12) that may be important to Joshua trees.

The cumulative effects of climate change are complex, on-going, and are likely to be of high magnitude in the future, particularly at low elevations and latitudes. There is currently evidence of decreased vigor and direct adult tree mortality due to increasing temperatures and drought conditions at lower latitudes. Stressed trees are at a higher risk for damage and mortality due to both wildfires and predation (discussed further below); and long-term survival is reduced when wildfires are followed by drought conditions. Increased risk of wildfire is projected with the potential for moderate and high severity fires in areas identified as climate refugia. There is evidence that flowering and recruitment conditions are changing under the current effects of climate change that are forecasted to increase, though masting reproductive events continue to occur several times a decade. There are regulatory mechanisms in place that help protect habitat and provide protective measures for Joshua trees, but few regulations exist that specifically address the threat of climate change (Appendix B). Therefore, while existing regulatory mechanisms and current conservation efforts may contribute to reduced greenhouse gas emissions in the United States, impacts from this threat is likely to increase in the future.

6.5 Predation and Herbivory

Joshua trees experience predation and herbivory, some of which is beneficial, to open fruits and distribute seeds, and some of which is negative, when numerous animals utilize adult plants in drought conditions. The threat and magnitude of predation varies depending on the phenology and age-class of the individual and the severity increases during drought conditions (Figure 6-6). We have no information on diseases that may impact Joshua trees.

6.5.1 Seed Predation

Joshua trees have coevolved with their specific yucca moth pollinators but there are also two additional moth species that oviposit on Joshua tree flowers, bogus moths and *Tegeticula corruptrix*, neither of which provide pollination services (Althoff *et al*. 2004, p. 324; Smith 2022, pers. comm.). *Tegeticula corruptrix* oviposit within the flower and potentially compete with yucca moths for receptive flowers. They also feed on fertilized seeds reducing the reproductive output and have been known to decimate seed crops in a given area (Smith 2022, pers. comm.). Bogus moths lay their eggs on the outside of the flower; though they are not a direct competitor with the yucca moths, they have the potential to damage the flower and limit reproduction. We currently lack information to characterize the abundance and potential reproductive impacts of the bogus moth. Joshua trees can limit the egg load of all moth predators by abscission of flowers with high egg loads, but that comes at the cost of losing all reproductive potential of those flowers. In a non-masting year, seed predation was more than two times higher than a masting year, based on the percentage of fruits infested (Borchert and DeFalco 2016, p. 832).

Table 6-3. Summary of bioclimatic models considered in this analysis.[1]

Study	Study Area	Species	Timeframe	Lower emissions scenario	Percent Decline in Modeled Habitat	High emissions scenario	Percent Decline in Modeled Habitat
Sweet *et al*. 2019	JTNP + Mojave Land Trust to the north 5km	YUBR	2070-2099	RCP 4.5	81.41	RCP 8.5	99.98
Barrows and Murphy-Mariscal 2012	JTNP and 10km buffer	YUBR	undefined	+3.6° F (2° C); +5.4° F (3° C)	66-78; 90-98	-	-
Thomas *et al*. 2012	southwest, multiple species study	YUBR, YUJA combined	2040-2069; 2070-2099	B1; A1B	88.6; 84.8	A2	94.9
Cole *et al*. 2011	Range-wide	YUBR, YUJA combined	2070-2099	A1B	up to 90	-	-
Dole *et al*. 2003	Range-wide + 100km buffer	YUBR, YUJA combined	undefined	future climate with enhanced freezing tolerance	71	-	-
Shafer *et al*. 2001	Range-wide (study addressed multiple species)	YUBR, YUJA combined	2090–99	IPCC IS92a	unquantified; >80 percent	-	-

[1] Appendix F provides detailed information on each model including the timeframe and GCMs utilized. We acknowledge that projected outcomes vary depending on the GCMs used in the model. Our analysis of future conditions is structured around the general consensus in the relative decline in climatically favorable habitat across all models for both a low and high emission scenario. All models were considered with the exception of Thomas 2022b, pers. comm.), because there was a large discrepancy between the current distribution and the modeled current distribution used in the analysis (Appendix G). Emission scenarios not modeled are indicated by a "-".

Joshua trees' dispersal relies on a balance of seed predation and seed-caching by a suite of rodents because the indehiscent fruits do not open on their own. The proportion of seeds cached and potentially available for germination compared to the number of seeds consumed varies dramatically depending on whether it is a masting year, average year, or a drought year. Masting events are believed to be an adaptation to improve recruitment by satiating predators (Borchert and DeFalco 2016, pp. 831, 835). In a non-masting year under drought conditions, fruits were readily collected and potentially consumed before caching. High rates of seed predation by rodents are also presumed to reduce the amount of seeds available for germination (Esque *et al*. 2010, p. 11).

Masting events are uncommon and limited to several events per decade on average (Esque *et al*. 2010, p. 9), though low to moderate levels of reproduction occur in most years. During the intervening years between masting events, seed predation by both moths and rodents has a larger impact on Joshua tree reproductive potential because it can take 2 to 3 years for an individual tree to amass enough resources to flower. The potential impacts on reproductive fitness are exacerbated under drought conditions and are currently occurring range-wide (Esque 2022a, pers. comm.). Seed predation occurred historically throughout the range of Joshua trees, and we do not have data to characterize how current threat levels compare to historical conditions or how the current threat level may impact abundance or the species' distribution. The severity of seed predation likely varies with site specific conditions and may be higher in warmer, low elevation portions of Joshua trees' distribution in the future. Our assessment is also constrained by the lack of information regarding the quantity of seed required to ensure that Joshua tree populations are resilient and maintain or increase their abundance.

6.5.2 Plant Herbivory

Due in large part to its high-water content, Joshua trees are susceptible to herbivory at all life stages and herbivory at younger age-classes often results in death (Figure 6-5). Herbivory is highest in young age classes and in clonal sprouts, due to their small stature and limited biomass, which may impact post-fire recovery (St. Clair *et al*. 2022, p. 4). Herbivory by large animals such as jackrabbits, cattle, and deer will kill entire individuals as will congregations of grasshoppers (Esque 2022a, pers. comm.). There is particularly high predation pressure by jackrabbits at these stages which limits recruitment (Lenz 2001, p. 71). Similar herbivore pressures occur at the juvenile stage with the addition of gophers, ground squirrels and wood rats, though herbivory is less likely to result in mortality compared to the earlier life stages (Esque 2022a, pers. comm.). Younger and smaller plants, less than 10 in (25 cm) tall had lower life expectancy and were more susceptible to herbivory especially in consecutive years of drought than taller individuals (Esque *et al*. 2015, p. 89). At this life stage, Joshua trees also become vulnerable to Yucca giant skipper larvae (*Megathymus* sp.) that develop tents and initially feed on the leaves of the apical meristem and older larvae feed on the root crown (University of Florida 2022, unpaginated; Esque 2022a, pers. comm.). Little is known about the effects of the Yucca giant skipper but death and reduced fitness has been correlated with apical meristem damage in other plant species (Adhikari and Russell 2014, p. 2085; Esque 2022a, pers. comm.).

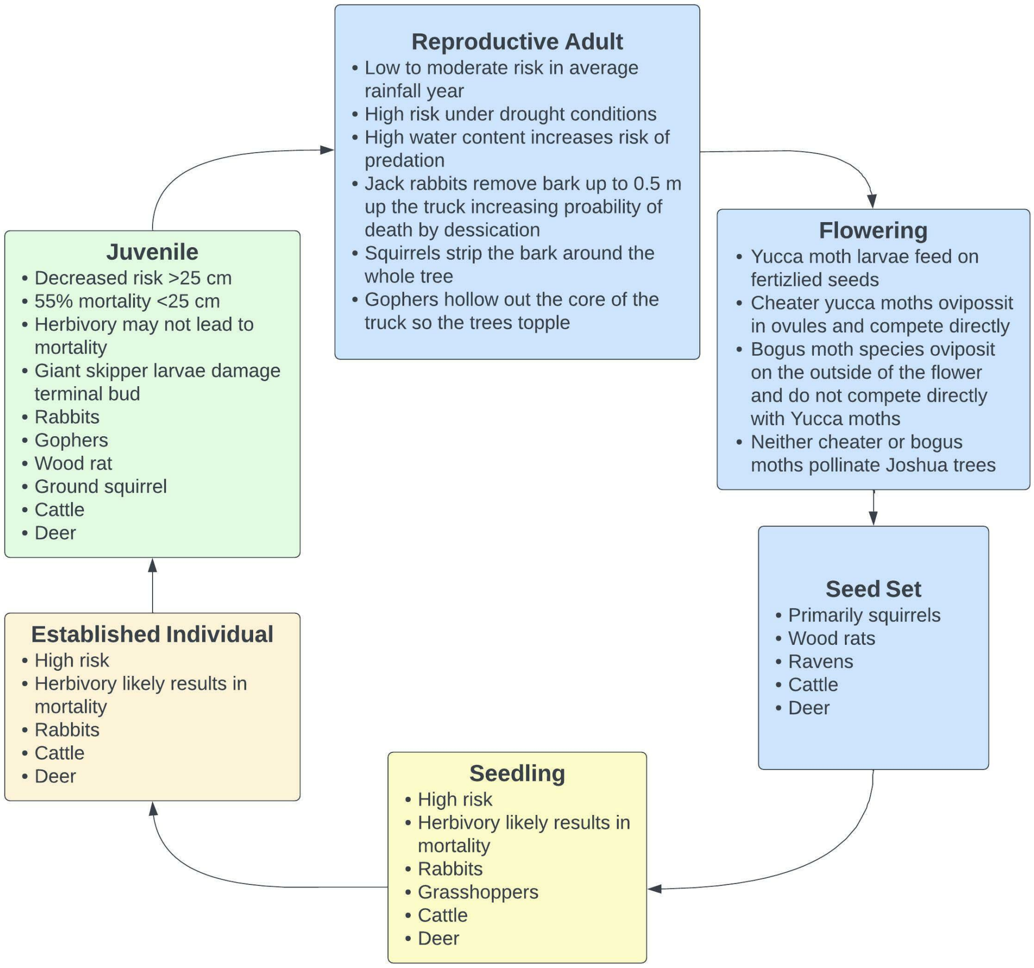

Figure 6-6. Predation and herbivory risk by life stage and phenology.[5]

Adult Joshua trees are also susceptible to herbivore damage and death, particularly under drought conditions. In drought years, small mammals that typically forage on seeds, fruits, shoots, and roots of native plants shift foraging pressure to Joshua trees (Esque *et al*. 2003, p. 2). The type of damage varies by species of herbivore. Antelope ground squirrels (*Ammospermophilus leucurus*) and black-tailed jackrabbits (*Lepus californicus*) were first documented to remove the periderm around the tree trunks in JTNP in 2002, following a year of extreme low rainfall (approximately 20 percent of average rainfall). Loss of the periderm exposes the vascular tissue increasing the risk of desiccation and death. *Thomomys bottae* (Pocket gophers) eat the roots and inner trunk, hollowing it out until the tree topples over (Figure 6-7). Impacted trees did not survive when greater than 25 percent of the periderm was removed and greater than 50 percent of the trees with any degree of damage died (Esque *et al*. 2003, p. 7). Within JTNP, the area under threat of periderm damage increased over the course of the drought period until trees in all areas of the park showed some level of damage. Similar damage and tree mortality is currently reported in other areas of the ranges of Joshua trees (Cornett 2020, p. 109; Jesus 2022, *in litt*.) and is

[5] Input and review provided by Todd Esque (USGS; Esque *et al*. 2015, entire; Esque 2022a, pers. comm.).

hypothesized to be an indication of the potential for changing interspecific dynamic with increasing temperatures and prolonged drought projected with future climate change (Esque 2022a, pers. comm.), though we do not have data on the magnitude of the threat rangewide. We expect some degree of herbivore damage occurred historically, but current anecdotal observations indicate that the current threat level is higher than experienced in the recent past. The extent of the damage may have impacts on demography with the potential loss of thousands of trees; and the combined effects of drought and herbivore damage may exceed the effects of a moderate intensity wildfire (Esque *et al*. 2003, p. 9; Cornett 2020, p. 109). However, we lack data on severity of herbivore damage throughout the range of Joshua trees as well as any potential impacts to the distribution and demography. USGS is currently implementing a demographic study that will include an assessment of tree condition through the distribution of Joshua trees, we expect that information to be available in 2023.

Herbivory occurs throughout the range of Joshua trees with the potential for higher impacts at lower elevations. Although Joshua trees have evolved in desert systems with this suite of predators and herbivores, there is evidence that the strength and direction of interspecific interactions increase under drought conditions and are currently more prevalent than previously reported. The impacts on adult trees are relatively recent and we do not have information on the magnitude of that threat throughout the range. There is evidence that warming temperatures and prolonged droughts are exacerbating impacts of herbivory and seed predation along the southern distribution within YUBR South.

6.6 Conservation

Joshua tree occupied habitat includes lands conserved as open space and resource lands owned by the Federal government, State agencies, and nonprofits, including conservation easements. Conservation is categorized by the protected area database (USGS 2018, unpaginated) based on how the lands are managed. Status 1 includes habitat that is permanently protected from habitat conversion and a mandated management plan is in place to maintain natural conditions, including disturbance events such as wildfire. Status 2 is similarly protected but management practices may suppress natural disturbance cycles such as wildfire or native pest outbreaks. Status 3 also provides for permanent projection but allows for low intensity uses such as OHV recreation or isolated high intensity uses such as mining. Based on the national inventory of protected areas (USGS 2018, unpaginated) approximately 3-million ac (1.2-million ha; 32 percent) of Joshua tree occupied habitat is fully conserved in Status 1 and 2 including 23 percent of *Yucca brevifolia* and 41 percent *Y. jaegeriana's* distribution. Considering lands that are protected with allowable low intensity or isolated impacts the percentage increases to 75 percent including 59 percent of the range of *Y. brevifolia* and 89 percent of the range of *Y. jaegeriana*. We consider that Joshua tree is largely conserved and the potential for habitat conversion is minimal across Status 1, 2 and 3.

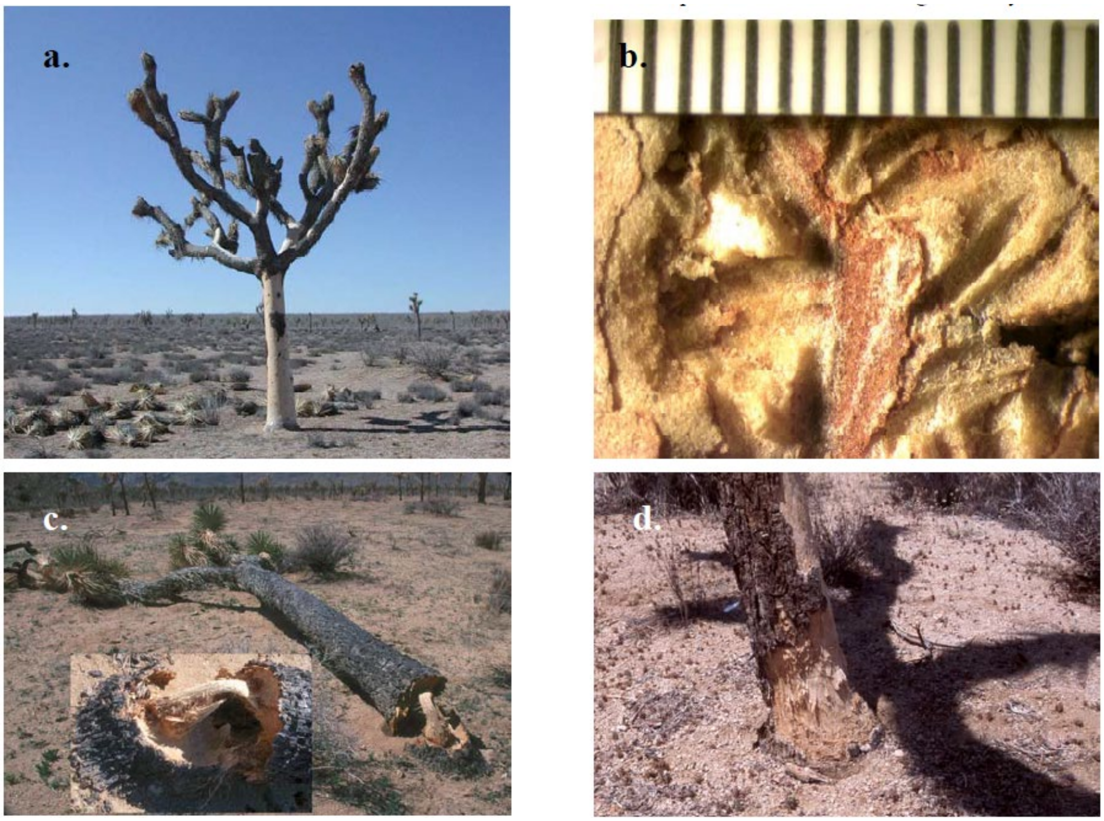

Figure 6-7. Examples of herbivory impacts and sources of mortality in Joshua tree (Esque *et al.* 2003, p. 6; with permission): (a) top left shows periderm removed, (b) top right shows rodent tooth marks on periderm, (c) bottom left shows gopher damage and tree mortality, (d) bottom right shows damage by black-tailed jackrabbits.

Table 6-4. Summary of conservation status based on the database of protected areas; (USGS 2018, unpaginated).

Analysis Unit	Status 1[a]	Status 2[a]	Status 3[a]	Not Protected[a]	Total 1 & 2[a]	Percent 1 & 2	Total 1-3[a]	Percent 1-3
YUBR North	458,015 (185,431)	165,838 (67,141)	893,317 (361,667)	611,943 (247,750)	623,854 (252,572)	29	1,517,171 (614,239)	71
YUBR South	339,400 (137,409)	39,008 (15,793)	727,964 (294,722)	1,181,790 (478,457)	378,408 (153,202)	17	1,106,372 (447,924)	48
YUBR Total	**797,415 (322,840)**	**204,847 (89,934)**	**1,621,281 (656,389)**	**1,793,733 (726,208)**	**1,002,262 (405,774)**	**23**	**2,623,543 (1,062,163)**	**59**
YUJA North	157,622 (63,812)	886,807 (359,031)	978,890 (396,312)	42,157 (17,068)	1,044,429 (422,846)	51	2,023,319 (819,157)	98
YUJA Central	425,260 (172,170)	514,758 (208,404)	946,522 (383,207)	202,623 (82,034)	940,017 (380,574)	45	1,886,540 (763,781)	90
YUJA East	22,073 (8,936)	0	451,772 (182,904)	280,975 (113,755)	22,073 (8,936)	3	473,846 (194,840)	63

Analysis Unit	Status 1[a]	Status 2[a]	Status 3[a]	Not Protected[a]	Total 1 & 2[a]	Percent 1 & 2	Total 1-3[a]	Percent 1-3
YUJA Total	**604,955 (244,921)**	**1,401,565 (567,435)**	**2,377,184 (962,423)**	**525,755 (212,356)**	**2,006,520 (812,356)**	**41**	**4,383,704 (1,774,779)**	**89**
Hybrid Zone	2,259 (951)	0	114,243 (46,252)	4,646 (1,881)	2,259 (915)	2%	116,501 (47,166)	96
Grand Total	**1,404,629 (568,676)**	**1,606,411 (650,369)**	**4,112,708 (1,665,064)**	**1,254,572 (507,924)**	**3,011,040 (1,219,045)**	**32**	**7,123,748 (2,884,109)**	**75**

[a] ac (ha)

Table 6-5. Summary of the magnitude of the threats to Joshua tree with each analysis unit based on the scope, intensity, likelihood and immediacy.

Threat	Habitat Loss and Degradation	Invasive Grasses	Risk of Wildfires	Climate Change	Predation and Herbivory
YUBR North	Low	Low to Moderate	Moderate	Low to Moderate	Low
YUBR South	Low+	Low	Moderate+	Moderate+	Low to Moderate+
YUBR Summary	**Low**	**Low to Moderate**	**Low to Moderate**	**Low to Moderate**	**Low to Moderate**
YUJA North	Low	Moderate+	Moderate to High+	Low to Moderate	Low
YUJA Central	Low	Low	Moderate to High	Low to Moderate	Low
YUJA East	Low	Low	Low	Low to Moderate	Low
YUJA Summary	**Low**	**Low to Moderate**	**Moderate**	**Low to Moderate**	**Low**
Hybrid Zone	Low	Moderate+	Moderate	Low to Moderate	Low
Overall magnitude of threat	**Low**	**Low to Moderate**	**Moderate**	**Low to Moderate**	**Low**

+ Indicates those analysis units where the magnitude of the threat is the greatest.

CHAPTER 7. CURRENT CONDITIONS

In this section we assess Joshua trees' current condition by evaluating resiliency, representation, and redundancy. To assess current conditions for *Yucca brevifolia* and *Y. jaegeriana*, each species' range was divided into analysis units. There are two analysis units for *Y. brevifolia* (YUBR North, YUBR South) and three analysis units for *Y. jaegeriana* (YUJA North, YUJA Central, YUJA East); a small Hybrid Zone was analyzed separately. Each of these units are representative of the range of biotic and abiotic features of Joshua tree habitat. A high overall resiliency condition score means all population resource needs are clearly adequate in the analysis unit; a medium overall resiliency condition score means some population resource needs are minimally present while others may be met in the analysis unit; and an overall low current resiliency condition means that one or more population needs are not adequate in the analysis unit.

7.1 Current Resiliency

Resiliency is the ability of populations to respond to stochastic events despite the current level of threat (described in the previous section). For the purposes of this analysis, our evaluation of population resiliency occurs at the scale of the individual analysis units (e.g., YUBR South). For this current population resiliency analysis, we considered the habitat and demographic needs required by Joshua trees to fulfill all aspects of its life cycle, where there is sufficient data to assess conditions across the multiple analysis units including aspects of habitat quantity, habitat quality and demography, described further below. Habitat needs, including appropriate substrate, precipitation, appropriate temperature ranges, nurse plants, pollinators and rodent seed-caching, are incorporated into the condition categories for habitat quantity and habitat quality. The demographic need for abundance is addressed by tree density and recruitment is characterized by the percentage of trees that are less than 3.3 ft (1 m; juvenile). This analysis is typically presented in the context of historical conditions, but we do not have historical data to inform that comparison.

Population resiliency was assessed within the six analysis units across the range of Joshua trees including two within the distribution of *Yucca brevifolia*, three within the distribution of *Y. jaegeriana*, and the Hybrid Zone (assessed independently; Figure 2-2). Based on the habitat and demographic needs identified earlier in the SSA, condition categories were defined where there was sufficient information to describe low, moderate, and high condition (Table 7-2). The analysis units were then assessed to evaluate population resiliency based on these categories (Table 7-3).

7.1.1 Summary of Methods

In order to develop condition categories, we used the best available scientific information on species needs, including research papers, survey reports, models, and feedback from species experts. Our approach for characterizing the quantity of occupied habitat, invasive grass cover, abundance and recruitment are summarized below.

7.1.1.1 Quantity of Occupied Habitat

Our analysis relies on recent USGS estimates of the area occupied by Joshua trees that is based on empirical evidence of where both species occur (Esque 2022b, pers. comm.). We consider areas currently occupied to indicate analysis units where the habitat needs are currently being met, though we acknowledge that species needs such as recruitment may be reduced or limited in in some areas. We also acknowledge that Joshua trees may persist in the future in areas where they are functionally extirpated because all or a portion of the species needs (e.g., sufficient pollinators, survival, and appropriate recruitment conditions to maintain population abundance) are not met. Therefore, we project future areas of habitat degradation separate from climate refugia, areas of habitat projected to be climatically favorable where all the species needs (e.g., sufficient pollinators, survival, and appropriate recruitment conditions to maintain population abundance) are forecasted to be met in the future. We defined thresholds based on attribute criteria for assessing species level adaptive capacity from Thurman *et al*. (2020, entire). Specifically, guidelines for categorizing the extent of an occurrence or population defines high habitat quantity as greater than 20,000 km^2 [4,942,108 ac (20,000 ha)] which is correlated with high species adaptive capacity; moderate habitat quantity as between 5,000 and 20,000 km^2 [1,235,527 and 4,942,108 ac (500,000 and 2,000,000 ha)]; and low habitat quantity as less than 5,000 km^2 [1,235,527 ac (500,000 ha)]. Based on this description, we made the assumption that the area of occupied habitat of both *Yucca brevifolia* and *Y. jaegeriana* has high condition for habitat quantity at the species level. We then divided this threshold by the number of analysis units for each species (two for *Y. brevifolia*; three for *Y. jaegeriana*) to assign the condition category at the level of the analysis unit. Therefore, high condition for habitat quantity is greater than 2,471,054 ac (1,000,000 ha) for *Y. brevifolia*; moderate is between 2,471,054 ac (1,000,427 ha) and 617,764 (250,107 ha); and low is less than 617,764 (250,107 ha; Table 7-1). For *Y. jaegeriana*, high condition is greater than 1,647,369 ac (666,951 ha); moderate is between 1,647,369 ac (666,951 ha) and 411,842 ac (166,738 ha); and low is less than 411,842 ac (166,738 ha). The Hybrid Zone was evaluated on the same scale as *Y. jaegeriana*.

7.1.1.2 Invasive Grass Cover

Habitat quality was assessed based on the percent invasive grass cover (Comer *et al*. 2013b, Figure 2); because invasive grasses have the potential to reduce soil moisture and increase the risk of wildfire. Invasive grass cover was modeled for the Mojave Basin and Range and Great Basin Desert ecoregions based on 2011 occurrence data. This model did not incorporate the Sonoran Desert ecoregion therefore the southern portion of *Yucca jaegeriana* distribution in northwest Arizona was not modeled. This data source is consistent with the approach utilized in the previous SSA; though we acknowledge through peer review comments that it may not adequately capture current conditions in all areas of Joshua trees' distribution. We ranked the southern analysis unit based on the proportion modeled. Similarly, some percentage of habitat was not modeled in each analysis unit and our assessment for the analysis unit is based on the proportion modeled. We used two aspects of the modeled invasive cover data to assess habitat quality: no/low (<15 percent) risk of invasive grass cover indicate undisturbed habitat, and a high (>15 percent) risk of invasive grass cover is associated with increased wildfire risk (Table 7-2) (Link *et al*. 2006, p. 116; Bradley *et al*. 2018, p. 1502). High quality habitat was indicated by a high proportion of the analysis unit (greater than 50 percent) with no/low risk of invasive grass cover and a low proportion (less than 10 percent) of increased wildfire risk. Moderate habitat quality was indicated by a moderate proportion of the analysis unit (25 to 50 percent) at no/low risk for invasive grasses and a moderate proportion (10 to 30 percent) with increased wildfire risk. Similarly, low quality habitat was indicated by a small proportion of the analysis unit (less than 25 percent) characterized as no/low risk and a high proportion (greater than 30 percent) with increased wildfire risk. Threshold values for the proportion of analysis units with different cover types were assigned to each category based on the range of the observed values.

7.1.1.3 Abundance

The demographic need for abundance was assessed using the average adult tree density based on two demographic studies that sampled across the range of Joshua trees' distribution (Esque *et* *al*. 2010, entire; St. Clair and Hoines 2018, entire), though we acknowledged that there are a limited study sites in several analysis units. Study sites are cross-referenced with the analysis units in Table 7-1. Tree densities varied by an order of magnitude, from 7.4 to 115 adult trees per ac (18.2 to 284 trees/ha), and was negatively correlated with temperature (St. Clair and Hoines 2018, p. 8). We lack information on the adult tree density required to maintain a population and other historical data to support the delineation of condition categories. However, we presume that sites with higher densities of Joshua trees such as Cima Dome are indicative of what might constitute the range of higher condition. Therefore, we defined high condition as greater than 40 adult trees/ac (100 trees/ha), moderate condition between 20 to 40 trees/ac (50 to 100 trees/ha), and low condition as less than 20 trees /ac (50 trees/ha). Analysis unit summaries describe whether current threats are having a potential impact on tree density.

7.1.1.4 Recruitment

The recruitment condition category was assessed based on one range-wide study sampling of Joshua tree demography (St. Clair and Hoines 2018, entire), though we acknowledged that there are a limited number of study sites in several analysis units. Recruitment in that study was characterized as the percent of the tree density data attributable to trees less 3.3 ft (1 m) tall (Table 7-1). This height category is indicative of the proportion of Joshua trees at each site that are in the juvenile age class, and we are not able to characterize recruitment inclusive of seedlings and established individuals based on this study. The range-wide study included information on flowering and seed set, but establishment rates tend to be low and variable in these species and therefore proportion of juveniles may be more indicative of recruitment into the next generation. The study did not sample in the Hybrid Zone, so we have no recruitment information for that area.

Table 7-1. Summary of recruitment parameters used to characterize current condition.[1]

Analysis Unit—Site—Study	Density trees/ha (trees/ac)	Percent Juvenile
YUBR North Goldfield, NV St Clair and Hoines 2018	31.0 (12.6)	15
YUBR North Lida, NV St Clair and Hoines 2018	246.5 (99.8)	20
YUBR North Death Valley NP, CA Esque *et al*. 2010	62.0 (25.1)	-
YUBR North Average	**113.2 (45.8)**	**17.5**
YUBR South Joshua tree E, CA St Clair and Hoines 2018	18.2 (7.4)	8.3
YUBR South Joshua tree W, CA St Clair and Hoines 2018	95.5 (38.7)	19

Analysis Unit—Site—Study	**Density trees/ha (trees/ac)**	**Percent Juvenile**
YUBR South Walker Pass, CA St Clair and Hoines 2018	284.3 (115.1)	18
YUBR South Joshua tree NP, CA Esque *et al*. 2010	95.2 (38.5)	-
YUBR South Average	**123.3 (49.9)**	**15.1**
YUJA North Beaver Dam, UT St Clair and Hoines 2018	35.1 (14.2)	6.6
YUJA North Grand Canyon, AZ Esque *et al*. 2010	37.2 (15.1)	-
YUJA North Average	**36.1 (14.6)**	**6.6**
YUJA Central Pahrump, NV St Clair and Hoines 2018	45.4 (18.4)	17
YUJA Central Searchlight, NV St Clair and Hoines 2018	66.9 (27.1)	7.5
YUJA Central Cima Dome, CA St Clair *et al*. 2018	189.8 (76.8)	8.3
YUJA Central Mojave NP, CA Esque *et al*. 2010	83.6 (33.8)	-
YUJA Central Lake Mead, NV Esque *et al*. 2010	30.8 (12.5)	-
YUJA Central Average	**83.3 (33.7)**	**10.9**
YUJA East Hwy 93, AZ St Clair *et al*. 2018	41.9 (17.0)	7.5
YUJA East Average	**41.9 (17.0)**	**7.5**

[1] Abundance is based on the density of trees per hectare and recruitment is characterized by the proportion of the tree density that are juveniles defined as less than 3.3 ft (1 m). Density data provided by St Clair *et al*. 2018 and Esque *et al*. 2010 (Esque *et al*. 2010, entire; St. Clair and Hoines 2018, entire). Percent juvenile data only provided by St Clair and Hoines (2018).

The proportion of juveniles ranged from 6.6 to 20 percent based on tree densities that ranged from 14 to 115 trees per ac (35.1 to 284.3 trees/ha; excluding Esque *et al* 2010). Based on the wide range of tree densities recorded and geographic range of the study, we consider the presence of juveniles to represent successful recruitment approximately 20 to 30 years ago. But we lack information on survival at each age class to adequately characterize the proportion of juveniles necessary to ensure that populations are stable or increasing, especially when the potential impacts of threats are considered. We also lack historical data and other context to categorize the available demographic data in terms of population resiliency, though a study is proposed to obtain range-wide estimates of abundance, age structure, and survival rates at study sites within the National Park Service system (Esque 2022a, pers. comm.). We do not have evidence that the current range of data reflects a high condition, and the current threat information suggests that some unquantified level of threat pressure has been exerted on these analysis units overtime. This assumption is based on site specific studies in YUBR South that have documented recent mortality from drought, predation, and herbivory (Esque *et al*. 2003, entire; DeFalco *et al*. 2010, entire; Cornett 2019, entire); as well as reduced recruitment (Barrows and Murphy-Mariscal 2012, entire; Sweet *et al*. 2019, entire; Graver 2022, entire), including recent data suggesting that the current rate of mortality is higher than recruitment (Cornett 2019, entire; Graver 2022, entire). Therefore, the portion of juvenile trees was divided into three categories (Table 7-2); greater than 15 percent of the tree density attributable to juveniles was considered high condition, 8–15 percent of the tree density attributable to juveniles was considered moderate condition and less than 7 percent was considered low condition.

Table 7-2. Current Condition Categories.

Condition	Quantity of Occupied Habitat	Habitat Quality Invasive Grass Cover	Abundance	Recruitment
High	YUBR> 2,471,054 ac (1,000,000 ha) YUJA> 1,647,369 ac (66,951 ha)	>50 percent of the area analysis unit with no/low invasive cover (<15 percent); <10 percent of the area of the analysis unit with high (>15 percent) invasive cover	> 40 adult trees/ac (100 adult trees/ha)	>15 percent juvenile trees
Moderate	YUBR between 617,764 and 2,471,054 ac (250,107-1,000,000 ha) YUJA between 411,842 and 1,647,369 ac (166,738-666,951 ha)	25-50 percent of the analysis unit with no/low invasive cover; 10-30 percent of the analysis unit with high invasive cover	20-40 adult trees/ac (50-100 adult trees/ha)	8-15 percent juvenile trees
Low	YUBR< 617,764 ac (250,107 ha) YUJA <411,842 ac (166,738 ha)	<25 percent of the analysis unit with no/low invasive cover; >30 percent of the analysis unit with high invasive cover	< 20 adult trees/ac (< 50 adult trees/ha)	<7 percent juvenile trees

We identified four condition categories including one habitat quantity parameter, one habitat quality parameter, and two demographic parameters. Each parameter was scored as high (5), medium (3), or low (1) based on the category descriptions above; intermediate scores were ranked moderate to high (4) or low to moderate (2). All categories contribute equally to population resiliency and the average was calculated across all condition categories to determine the overall resiliency score. A high overall resiliency condition score (3.6 to 5.0) means all population needs are clearly met across all condition categories within the analysis unit and that the analysis unit is resilient to environmental variation in the range experienced by the species in the recent past (Table 7-3); a highly resilient analysis unit is unlikely to become extirpated and is more likely to contribute to species viability. A medium overall resiliency condition score (2.1 to

3.5), means some habitat or demographic needs are minimally present in the analysis unit; but we expect that the analysis unit likely has the resiliency necessary to recover from stochastic variability. Although occupancy may be lost in some areas, it is unlikely to become extirpated and the functionality of the unit is likely to be retained. An overall low population resiliency condition score (0 to 2) means that one or more habitat or demographic needs were not met or all needs are at such low condition that there is a higher probability that the analysis unit may be extirpated; a low resiliency analysis unit is unlikely to contribute substantially to species viability. Condition for several analysis unit categories were exceptionally low and a very low conditions was added to acknowledge these circumstances.

Table 7-3. Current Population Resiliency within the Joshua tree Analysis Units

Condition	Quantity Of Occupied Habitat	Invasive Grass Cover	Tree Density	Recruitment	Total Score
YUBR North	Moderate To High	Moderate To High	Moderate To High	High	**High (4.3)**
YUBR South	Moderate To High	High	Moderate To High	Moderate To High	**High (4.3)**
YUJA North	High	Low To Moderate	Low	Low	**Moderate (2.3)**
YUJA Central	High	Moderate To High	Moderate	Moderate	**High (3.8)**
YUJA East	Moderate	Moderate	Low	Moderate	**Moderate (2.5)**
Hybrid Zone	Low	Moderate	NA	NA	**Low To Moderate (2.0)**

7.2 *Yucca brevifolia*

7.2.1 Population Resiliency

7.2.1.1 *Yucca brevifolia* North

The YUBR North analysis unit is considered highly resilient to stochastic events given the overall high resiliency score and current low magnitude of threats (Table 6-5, Table 7-3). The species is distributed throughout a moderate to high area of occupied habitat totaling 2,129,113 ac (861,989 ha) which confers increased resiliency. Approximately 29 percent is conserved, and 98 percent occurs on Federal lands (including 17 percent on military lands and 81 percent on lands managed by the BLM, National Park Service (NPS), Department of Energy, and the Forest Service) and we project a low potential for habitat loss. This analysis unit occurs to the north of the *Yucca brevifolia* distribution and includes the transition from the dry, desert regions of the Mojave Desert to a more temperate, intermountain desert region typical of the Great Basin Desert. On average YUBR North experiences lower levels of drought stress, because it occurs at higher latitudes, and is presumed to experience a lower magnitude of threat due to predation and herbivory related to drought conditions. With respect to habitat quality, approximately 55 percent of the analysis unit is characterized by no to low risk of invasive grasses and high invasive risk was modeled on approximately 16 percent of the analysis unit resulting in a moderate to high ranking overall. The areas of high wildfire risk and estimated high burn severity occur to the north in areas of potential climate refugia and are interspersed and adjacent to habitat that has not burned for greater than 300 years. Abundance is currently considered high in YUBR North based on average high tree density [45.8 trees/ac (113.2 trees/ha)]; but we reduced the condition to moderate to high to more accurately reflect the tree density across the analysis unit rather than rely on the average value which was driven by a single high-density site that is likely not representative of the analysis unit [Lida, Nevada; 104 trees/ac (257 trees/ha)]. In the absence of this site, the tree density would have been ranked low. YUBR North is considered high for recruitment with an average of 17.5 percent of tree density attributable to juveniles (range from 15 to 20 percent).

7.2.1.2 *Yucca brevifolia* South

The YUBR South analysis unit is considered highly resilient to stochastic events given the current low to moderate magnitude of threats; and the condition categories were modified to include analysis unit specific studies on mortality and recruitment described below (Table 7-3). YUBR South is distributed throughout a moderate to high area of occupied habitat totaling 2,288,162 ac (926,381 ha) including moderate ecological variability. This analysis unit occurs in the southwest portion of *Y. brevifolia* distribution and primarily occurs within the dry, desert regions of the Mojave Desert. YUBR South currently experiences the highest levels of drought stress across the range of Joshua trees; drought stress levels are comparable in YUJA East, though YUBR South receives less summer precipitation. Approximately 17 percent of the analysis unit is currently conserved, and 52 percent occurs on Federal lands, including 15 percent on military lands and 38 percent on lands managed by the BLM, NPS, and Forest Service. YUBR South has the highest proportion of privately-owned land (46 percent) and therefore has the highest risk of habitat loss, though the State of California and local jurisdictions have regulations in place to avoid and mitigate potential losses, some of which are temporary while the species is a candidate for listing under the California Endangered Species Act. The unit has high habitat quality and approximately 52 percent of the analysis unit is characterized by no to low risk of invasive grasses including much of the federally owned land in the north and eastern part of the analysis unit. High invasive risk was modeled on only 2 percent resulting in a high habitat quality ranking overall. Although the areas of high invasive risk are small, they occur along the urban-wildland interface where there is currently evidence of more frequent wildfires on approximately 9 percent of the unit. Middle and high elevation vegetation communities within this analysis unit are characterized by an increased risk of high severity wildfires including areas that will likely serve as climate refugia and low elevations are characterized by low fire frequency, though the potential exists for higher human caused ignitions near developed areas. In summary, Joshua trees in this analysis unit are more susceptible to potential effects of drought and wildfire because the extended drought conditions, evidence of an increased wildfires along the urban-wildland interface, and the combined effects contribute to the potential for increased mortality and delayed post-fire habitat recovery, though conditions may be temporarily ameliorated to some degree during periods of average to high rainfall.

The analysis unit condition for demography was modified based on recent studies. Abundance was initially considered high in YUBR South based on high tree density [50 trees/ac (123.3 trees/ha)]

(Table 7-1). But the data is strongly influenced by high density at Walker Pass [115 trees/ac (284 trees/ha)] along the slopes of the Sierra Nevada, which is reported to have a high density of clones (Esque 2022a, pers. comm.) and is not representative of the habitat throughout the rest of the unit. In addition, preliminary data from a demographic survey of *Yucca brevifolia* in JTNP indicate there has been a 4.9 percent decline in population abundance at that site in the past 12 years (from 2008/09 to 2021) with mortality observed on 42 percent of the study plots (Graver 2022, entire). Similarly, at Red Rock Canyon State Park a 46 percent decline in the population was recorded as well as tree vigor and the percentage of young trees (Cornett 2019, pp. 9–10). Based on this information, we consider tree density to be moderate to high condition. Similarly, the data used to characterize condition categories supports moderate recruitment, based on an average of 15 percent juvenile trees. But there is evidence of limited to no recruitment of younger age-classes in this analysis unit (Esque *et al*. 2010, p. 11; Cornett 2019, p. 9), a reduction in the quantity of suitable recruitment habitat (Barrows and Murphy-Mariscal 2012, p. 34; Sweet *et al*. 2019, p. 7), and a lower rate of recruitment relative to mortality (19 seedlings were found compared to 42 trees that died within the survey plots; (Graver 2022, entire); based on this information recruitment condition was reduced from high to moderate. In consideration of recent, localized evidence of increased mortality, decreased recruitment and moderate to high habitat quantity and quality, we consider YUBR South to be highly resilient to stochastic variability and is forecasted to recover and maintain population resiliency over the course of current environmental variability including prolonged drought.

7.2.1.3 Summary

Yucca brevifolia occupies a large and diverse area of 4.4 million ac (1.8 million ha) in two analysis units of similar size within the western Mojave Desert that confers high population resiliency. Both YUBR North and YUBR South are considered highly resilient (Table 7-3). Within the mapped distribution of this population, there are approximately 2.6 million acres (1,046,365 ha; 74 percent) of Federal lands administered by the NPS, BLM, Forest Service, Department of Energy, and military lands. This population also includes several National (JTNP, Death Valley National Park), California State (Red Rock Canyon State Park), and County parks and preserves. The species is currently being managed and monitored at JTNP. The southern analysis unit (YUBR South) has a higher proportion of the area privately owned and potentially subject to development, though 52 percent is under Federal management. The species distribution occurs along a latitudinal gradient and the southern analysis unit is currently, and likely historically, more drought stressed and has a higher magnitude of threat associated with drought exacerbated predation and herbivory. There is also evidence that recruitment and the quantity of recruitment habitat is reduced at lower elevations in YUBR South, though demographic condition is moderate to high. In contrast YUBR north is characterized by lower temperatures and higher precipitation which contributes to higher recruitment condition and moderate to high demography overall. We consider that both populations currently have a high capacity to withstand or recover from stochastic disturbance events due to the large distribution, moderate to high tree demography, and large percentage of the distribution conserved or managed on Federal lands, though there is evidence that demographic and habitat conditions may have declined in recent years.

7.2.2 *Yucca brevifolia* Redundancy

We consider redundancy in *Yucca brevifolia* to be high. YUBR South and YUBR North are spread across a very large area of mostly intact habitat that supports resource needs. There is no evidence to indicate that a range contraction has occurred over the last 30 to 40 years, based on distribution mapping (Rowlands 1978, p. 52; Esque 2022a, pers. comm.). Although a systematic survey of abundance was not conducted across the range, the acres of occupied habitat suggests that the distribution is occupied by millions of Joshua trees distributed across a latitudinal gradient of approximately 300 mi (483 km). Additionally, habitat is located primarily on Federal lands where Joshua trees are often considered in facility operations or specifically managed for, and are less likely to be impacted by anthropogenic development. The risk of catastrophic loss is very low because the species is spread across a 4.4 million ac (1.8 million ha) area. Although there is recent site-specific evidence of reduced recruitment under extreme drought conditions, we do not anticipate that current redundancy is substantially reduced such that wildfire, prolonged drought, or extreme predation and herbivory will cause either analysis unit to be in danger of extinction.

7.2.3 *Yucca brevifolia* Representation

We evaluated representation in *Yucca brevifolia* based on the ecological diversity of the habitats it occupies, as a surrogate for genetic diversity, and the species' life history characteristics that support or hinder adaptive capacity (Appendix A). Adaptive capacity was evaluated following Thurman *et al*. (2020) to characterize *Y. brevifolia*'s ability to persist in place or shift in space in response to changes in its environment. Representation, as measured by the ecological diversity of habitats, is high as the two analysis units occupy highly diverse areas within the Mojave and Great Basin Deserts that include differences in elevation, aspect, soil type, temperature, rainfall, and vegetation communities. The large area that the species occupies, the broad latitudinal distribution, and lack of habitat specialization promote higher adaptive capacity. Recently documented reductions in recruitment and survival are site-specific and we do not have data to support range-wide trends. Therefore, we do not anticipate recent declines to substantially reduce abundance or representation. Across these different environmental gradients *Y. brevifolia* exhibits variability in growth and reproductive strategies including the relative proportion of asexual reproduction. Although clonal growth does not increase dispersal capabilities as it does in other species, the clonal growth strategy has been shown to increase persistence of the individual under stress—such as wildfire—which, along with the Joshua trees' long lifespan, is anticipated to facilitate the ability of *Y. brevifolia* to persist in place in response to long-term or slow changes in its environment. Joshua trees' long lifespan, limited reproductive events, long generation time, and extended age of sexual maturity limit the ability of *Y. brevifolia* to adapt to short term changes in its environment. Its adaptive capacity and the extent that its populations can persist in place in the face of variable environmental conditions are also constrained by its obligate mutualism with the yucca moth and we do not have information to assess the adaptive capacity of the yucca moth. Lastly, limited dispersal capabilities have been documented based on the average dispersal distances of the rodent seed dispersers and through the absence of substantial range expansion since the Holocene. Therefore, *Yucca brevifolia* is unlikely to be able to shift in space beyond average dispersal rates in response to changing environmental conditions. But the species has other life history characteristics that confer representation including high ecological variability and the capacity to persist under similar environmental conditions as it has experienced in the past. Although there is recent site-specific evidence of reduced recruitment under extreme drought conditions, the species currently has the capacity to withstand and adapt to changes in environmental conditions and masting vents have been recorded several times in the last decade.

7.3 *Yucca jaegeriana*

7.3.1 Population Resiliency

7.3.1.1 *Yucca jaegeriana* North

We consider the YUJA North analysis unit moderately resilient to stochastic events given the current low to moderate magnitude of threats (Table 7-3). This analysis unit occurs toward the northeast of *Yucca jaegeriana* distribution and includes the transition from the dry, desert regions of the Mojave Desert to a more temperate, intermountain desert region typical of the Great Basin Desert, similar to YUBR North; however, there is evidence of moderate drought stress at lower elevations in southern Nevada based on the climatic moisture index (Figure 3-9) and increases in the frequency of wildfire and area burned. The YUJA North analysis unit has high condition for habitat quantity and is distributed throughout a large area of occupied habitat totaling approximately 2,065,476 ac (836,225 ha). The actual area occupied may be different than reported here; we relied on our previous analysis in the SSA for the portion of the analysis unit not included in the updated USGS distribution information.

Approximately 51 percent is conserved, and 98 percent occurs on Federal lands including 5 percent on military lands and 93 percent on lands managed by the BLM, Service, and the NPS. Therefore, this analysis unit has a low potential for habitat loss. With respect to habitat quality, there are roughly equal amounts of low risk of invasive grasses (approximately 31 percent of the analysis unit) and high invasive risk (30 percent), resulting in a low to moderate ranking for this category. Higher invasive grass risk occurs in the northern limit of this analysis unit in areas where increased fire frequency is evident and in areas that have not burned for 300 years or more. Half of this analysis unit is characterized at high probability of natural ignitions and increased fire frequency and an additional third is at high risk of high severity wildfires. Abundance and recruitment have low condition in YUJA North based a tree density of 14.6 trees/ac (36.1 trees/ha) on average and 2.7 juveniles/ac (6.6 juveniles/ha) and are the primary drivers of the analysis unit's overall moderate resiliency score. The analysis unit's low demographic condition may limit its resiliency should threats continue or increase.

7.3.1.2 *Yucca jaegeriana* Central

We consider the YUJA Central analysis unit to be highly resilient to stochastic events given the current low magnitude of threats (Table 7-3). This analysis unit includes 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. There is some evidence of moderate drought stress at lower elevations based on the climatic moisture index (Figure 3-9). This analysis unit is distributed throughout a large area of occupied habitat totaling 2,089,163 ac (845,815 ha) considered high condition for habitat quantity. Approximately 45 percent of this unit is conserved, and 90 percent occurs on Federal lands including 1 percent on military lands and 89 percent on lands managed by the BLM, NPS, Forest Service, Bureau of Reclamation, and the Service. With respect to habitat quality, approximately 37 percent of the analysis unit is characterized by no to low risk of invasive grasses and high invasive risk was modeled on approximately 6 percent resulting in a moderate to high ranking for habitat quality. Half of this analysis unit is characterized at high probability of natural ignition and increased fire frequency and an additional third is at high risk of high severity wildfires. Abundance in YUJA Central is moderate based on an average tree density of 33.7 tree/ac (83.3 trees/ha), which is influenced by the particularly high density at Cima Dome, Nevada [76.8 trees/ac (189.8 trees/ha)]. Recruitment is considered moderate based on 10.9 percent of the tree densities attributed to the juvenile age class; and we have no additional information about recruitment in this analysis unit.

7.3.1.3 *Yucca jaegeriana* East

We consider the YUJA East analysis unit to have moderate resiliency to stochastic events given the current low magnitude of threat (Table 7-3), though we have the least amount of information on YUJA East and limited information on how drought stress is potentially affecting the species in this analysis unit. The YUJA East analysis unit is distributed throughout a smaller area of occupied habitat totaling 754,821 ac (305,595 ha). YUJA East is less topographically diverse and includes lower elevation areas that are currently experiencing moderate levels of drought stress based on the climatic moisture index (Figure 3-9). Approximately 3 percent of the unit is conserved and 60 percent of this occurs on Federal lands all of which are managed by BLM. Approximately 24 percent occurs on private land and potentially subject to development, with few regulations encouraging avoidance and mitigation. YUJA East has moderate habitat quality with 20 percent identified as low to no risk for invasive grasses and less than 1 percent considered high risk. This analysis unit is estimated to have low wildfire frequency and severity and burned habitat is less likely to fully recover due to drought conditions. Abundance is considered low in YUJA East based on tree density at one location of 16.9 trees/ac (41.9 trees/ha) and lower densities are correlated with warmer temperatures (St. Clair and Hoines 2018, p. 8). We do not know if tree density was historically low because we lack information on survival or mortality in this analysis unit. Based on the single study site on Highway 93, recruitment is characterized as moderate based on 3 juveniles/ac (7.5 juveniles/ha) and resiliency in this analysis unit is moderate overall.

7.3.1.4 Summary

Yucca jaegeriana is distributed across a 4.9 million ac area (1.9 million ha) in three analysis units across the eastern Mojave Desert and a small portion of the southern Great Basin Desert and western Sonoran Desert, which is considered high condition for habitat quantity at the species level. Approximately 89 percent of *Y. jaegeriana's* distribution occurs on federally owned or managed land; private land ownership accounts for 7 percent and primarily occurs in YUJA East. YUJA North has higher ecological diversity that the southern two analysis units combined, as these areas are more low lying and less topographically diverse. Like *Yucca brevifolia*, *Y. jaegeriana* occurs along a latitudinal gradient and the southernmost analysis unit is exposed to more drought stress and has the potential for higher drought exacerbated predation and herbivory, though we have limited data on how prevalent this threat is in *Y. jaegeriana* relative to historical conditions. YUJA East may be less resilient should the increased fire risk be realized, especially if wildfires are followed by drought conditions. YUJA East also has lower resiliency overall due to the smaller size of the analysis unit and low tree density and recruitment, though there are no to limited monitoring studies including this portion of the range of Joshua trees. We consider that *Y. jaegeriana* analysis units have moderate to high resiliency on average due to moderate to high habitat quantity, though some units have lower demographic condition currently and likely historically (Table 7-3).

7.3.2 Redundancy

Although we lack information to estimate the size of the population, we consider it reasonable to assume redundancy is also high in *Yucca jaegeriana*. YUJA Central, YUJA North, and YUJA East analysis units occur across a very large area of mostly intact habitat that support resource needs. There is no evidence to support a range contraction over the last 40 years based on distribution mapping (Rowlands 1978, p. 52; Esque 2022a, pers. comm.), though wildfire has impacted localized areas in YUJA North and YUJA Central. Additionally, plants are located primarily on Federal lands with less probability of development. The risk of catastrophic loss is very low because the species is spread across a 4.9 million ac area (1.9 million ha) distributed over a latitudinal gradient of approximately 300 mi (483 km) and includes potentially millions of individual trees and clones. Although there is recent evidence of localized wildfire impacts and the invasive grass-wildfire cycle, we do not anticipate that current redundancy is substantially reduced such that wildfire, prolonged drought, or extreme predation and herbivory would extirpate an analysis unit of *Y. jaegeriana*.

7.3.3 Representation

We also evaluated representation in *Yucca jaegeriana* with respect to ecological diversity and life history characteristics that support or hinder adaptive capacity. Adaptive capacity was evaluated following Thurman *et al*. (2020) to characterize *Y. jaegeriana*'s ability to persist in place or shift in place in response to changes in its environment. The characteristics that support high persistence under slow or minor changes in the environment and limited adaptability and dispersal in *Y. brevifolia* discussed above, also apply to *Y. jaegeriana*. However, there is some preliminary evidence that *Y. jaegeriana* physical characteristics may make it more susceptible to wildfire (Cornett 2022b, pp. 186–188). Ecological diversity is also similar, as *Y. jaegeriana* occupies an extensive area covering approximately 300 mi (483 km) from north to south. There is a high degree of variability in abiotic and biotic conditions within these habitats. YUJA North has higher ecological diversity that the southern two analysis units combined, as these areas are more low lying and less topographically diverse. Ecological variability is somewhat reduced, both in topographic heterogeneity and the number of ecoregions, relative to *Y. brevifolia* currently and historically; but is not projected to substantially reduce the representation of the species. Similarly, the assessment of population resiliency highlighted the potential for lower tree densities and recruitment, particularly in the southern portion of the species' range; but we do not have any information regarding how this information compares to historical conditions or that it currently impacts representation. Therefore, we consider *Y. jaegeriana* to have sufficient representation to adapt to environmental conditions over time but may have limited dispersal capacity to shift in space beyond average dispersal rates to overcome more rapid or extreme variability. But the species has other life history characteristics that confer representation including high ecological variability and the capacity to persist under similar environmental conditions as it has experienced in the past. Although there is recent evidence of the loss of individuals due to wildfire, the species currently has the capacity to withstand and adapt to changes in environmental conditions.

7.4 Hybrid Zone Population Resiliency

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*. 2013, p. 3). The Hybrid Zone analysis unit is distributed across a 121,147 ac (49,047 ha) of occupied habitat which is low condition in terms of habitat quantity though it is contiguous to occupied *Yucca brevifolia* habitat to the west and *Y. jaegeriana* habitat to the east. The Hybrid Zone is located at higher latitude and is not characterized by the drought stress that as evident in the southern analysis units. Approximately 2 percent is conserved and nearly 100 percent occurs on Federal lands including 4 percent on military lands and 96 percent on lands managed by BLM. With respect to habitat quality the Hybrid Zone includes approximately 64 percent characterized by no to low risk of invasive grasses, the highest percentage of all the units analyzed; but it also has the highest proportion characterized as high invasive risk (32 percent), resulting in a moderate ranking for this category. The studies used to assess tree density and recruitment did not include study sites within the Hybrid Zone, so we cannot evaluate demographic needs for this analysis unit. However, increased dispersal distances have been observed in this analysis unit suggesting the possibility of limited range expansion. Overall, we consider the Hybrid Zone to have low resiliency largely due to the smaller size of the unit, though it is contiguous with other analysis units and occupied habitat. The Hybrid Zone contributes toward the redundancy and representation of both *Y. brevifolia* and *Y. jaegeriana*.

CHAPTER 8. FUTURE CONDITIONS

8.1 Future Scenario Considerations

Scenario planning is a comprehensive exercise that involves the development of scenarios that capture a range of plausible future conditions, which is then followed by an assessment of the potential effects of those scenarios on a given species. Scenarios are not projections or forecasts of what will happen in the future for a species but are projections or explorations into the range of conditions that may exist based on current information (Figure 8-1). The scenarios are intended to provide the "upper" and "lower" bounds of plausible conditions (Figure 8-2), outline uncertainties, and provide decision makers with a means for managing risk and maintaining flexibility in current and future decisions.

A range of time frames with a multitude of possible scenarios allows us to create a "risk profile" for Joshua tree and its viability into the future. While we do not expect every condition for each scenario to be fully realized, we are using these scenarios as examples for the range of possibilities. For each scenario, we describe the threats that would occur in each population and how they may change in the future. We used the best available science to project trends in future threats facing Joshua trees. Data availability varies across the range of the species and individual populations. Where data on future threats or trends are not available, we look to past threats and their trends. We evaluate if it is reasonable to assume these trends will continue into future and to what degree.

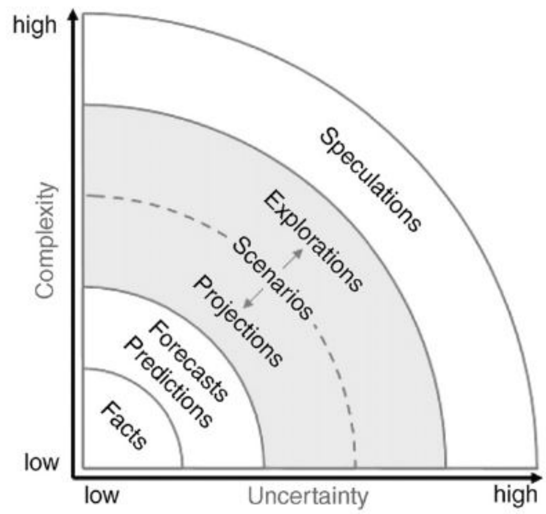

Figure 8-1. The levels of uncertainty and complexity in situations for which scenarios can be useful in considering future possibilities (adapted from Roland *et al.* 2014).

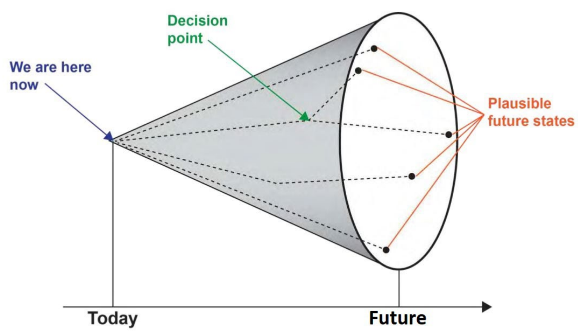

Figure 8-2. Conceptual diagram of the broadening range of plausible alternative futures as one moves farther away from the present and different events and decision points shift trajectories. (Roland *et al.* 2014).

In order to analyze future conditions, we developed two plausible scenarios to assess how the species needs, threats, and habitat conditions may change over the next 80 years at the end of the century. Plausible changes in threats associated with habitat loss including renewable energy development, invasive grass cover, climate change, and wildfire are summarized in Table 8-1 and discussed below. Grazing and OHV use were not carried forward as the magnitude of the threats is considered negligible in comparison to the threats included in the analysis and we lack information to characterize the magnitude of the current and future threat. The threats forecasted for each future scenario include habitat loss, invasive grasses, wildfire, and drought and increased temperatures associated with climate change. Table 8-1 summarizes the changes in the threats modeled relative to current conditions based on the data sources described above; and Table 8-2 summarizes the corresponding changes in the magnitude of each threat for the scenarios modeled.

Table 8-1. Plausible changes in primary threats identified in each of the two future scenarios.

Factors Influencing Viability	Scenario I: Similar to Current Threats 2070-2099	Scenario II: Increased Threats 2070-2099
Habitat Loss	A 20 percent average increase in the acreage under development across the range of Joshua trees (Environmental Protection Agency 2015)	A 25 percent average increase in the acreage under development across the range of Joshua trees[1] (Table 8-3; Environmental Protection Agency 2015)
Renewable Energy	Approximately 260,000 ac (105,218 ha) of additional development in YUBR North and YUBR South.	Approximately 230,000 ac (93,077 ha) of additional development in YUBR North and YUBR South.
Invasive Grass Cover	Current levels of modeled invasive grass cover (Comer *et al*. 2013b, Figure 2)	Projected increases in the invasive grass cover based on areas of increased risk of invasion (Comer *et al*. 2013b, Figures 2, 3)
Drought and Increased Temperatures	Estimated area of climatically unfavorable habitat and climate refugia based on climate models forecasting conditions for RCP 4.5: Climatically unfavorable: 60–80 percent Climate refugia: 20–40 percent	Estimated area of climatically unfavorable habitat and climate refugia based on climate models forecasting conditions for RCP 8.5: Climatically unfavorable: 80–99 percent Climate refugia: 1–20 percent
Wildfire Risk	Current increased risk of wildfire modeled on 12 percent of occupied habitat.	Current increased risk of wildfire modeled on 18 percent of occupied habitat.

[1] Under RCP 8.5, the acres of future development was modeled to be lower than RCP 4.5 based on future modeled human population growth, though we consider Scenario II to reflect increased threats.

Table 8-2. Current and projected changes in the magnitude of threats evalauted under future scenarios.

Threat	Current (2010-2022)	Scenario I	Scenario II
Habitat Loss and Degradation	Low magnitude, isolated impacts	Moderate increase	Moderate increase (Similar to Scenario I)
Invasive Grasses	Low to moderate, widespread impacts	Similar to Current Conditions	Moderate increase
Risk of Wildfire	Moderate, widespread risk	Moderate to high increase	Increased risk at high elevations, decreased risk at low elevations
Climate Change	Low to moderate, widespread threat	Moderate to high increase	High increase
Predation and Herbivory	Low magnitude	Moderate increase	Moderate to high increase

Future habitat loss was projected based on land use estimates from the Integrated Climate and Land Use Scenarios (ICLUS) database for RCP 4.5 and 8.5 (Environmental Protection Agency 2015). Development is projected to increase with increasing population densities represented by the change in the acreage designated as urban, suburban, and exurban including associated parks and transportation (Table 8-3). The increase in developed areas most often occurred in areas previously designated as grazing or rangeland that were occupied by Joshua trees on nonfederal lands. The analysis units with the highest proportion of current and projected future development are YUBR North and YUBR South. Projected increases are also forecasted for YUJA Central, and YUJA East, though the total acreage projected acreage is limited, approximately 60,000 ac (24,291 ha) and 10,000 ac (4,049 ha) respectively (Table 8-3).

Table 8-3. Current and projected changes in land use based on developed categories (Environmental Protection Agency 2015).[1]

Analysis Unit	Current Acres[2]	Percent of Analysis Unit Current	Acres Scenario I[2]	Percent of Analysis Unit Scenario I	Percent Change	Acres Scenario II[2]	Percent of Analysis Unit Scenario II	Percent Change
YUBR North	609,959 (246,423)	28.6	612,718 (247,538)	28.8	0.5	617,031 (249,281)	29.0	1.2
YUBR South	585,056 (236,363)	25.6	816,064 (329,690)	35.7	39.5	879,656 (355,381)	38.4	50.4
YUJA North	20,675 (8,353)	1.0	20,803 (8,404)	1.0	0.6	21,192 (8,562)	1.0	2.5
YUJA Central	41,255 (16,667)	2.0	50,811 (20,528)	2.4	23.2	58,247 (23,532)	2.8	41.2
YUJA East	4,612 (1,863)	0.6	10,807 (4,366)	1.4	134.3	6,490 (2,622)	0.9	40.7
Hybrid	6,941 (2,804)	5.7	6,941 (2,804)	5.7	0.0	6,941 (2,804)	5.7	0.0

[1] The amount of area designated as developed (urban, suburban, and exurban) under current and two future emissions scenarios are shown for each analysis unit, presented as total acreage, percent of analysis unit, and the percent change from current for the future scenarios.
[2] ac (ha).

With respect to potential habitat loss, we also projected future renewable energy development to a limited degree. In order to meet national renewable energy goals, millions of acres of utility-scale solar energy projects are projected in the future (Smith *et al*. In Review, p. 7). The solar energy goals for California are largely projected to be met by the DRECP (Smith *et al*. In Review, p. 7), which includes avoidance and minimization measures for Joshua trees; therefore, we project that the impacts to Joshua trees in these areas will be minimized and mitigated. However, most of the current renewable projects in California occur on privately owned land (60 percent). To account for potential renewable projects outside of the DRECP in California, we used the ICLUS dataset described above for development to forecast the acres of private land with a high probability of being developed for renewable energy in the future, based on where renewable energy projects are currently located in YUBR North and YUBR South. Depending on the scenario, between 19,711 and 23,716 ac (7,963 and 9,581 ha) are potentially developable in YUBR North and 438,639 to 500,908 ac (177,210 to 202,366 ha) in YUBR South, based on RCP 4.5 and 8.5, respectively. We projected that 50 percent of the available private land will be developed by the end of the century or a maximum of 260,000 ac (105,218 ha), in addition to the acreage forecasted for urban development. We do not have specific projections for renewable energy development outside of California and this analysis does not include forecasted habitat loss due to renewable energy development in Arizona, Nevada, or Utah.

Invasive grass cover is anticipated to increase in the future in current areas identified as high risk (>15 percent invasive grass cover) and in areas that are disturbed. Therefore, we project areas of low and high risk of invasive grasses to remain the same in the future unless low risk areas are disturbed. Future invasive grass cover was projected based on the Rapid Ecoregional Assessment for the Mojave Basin and Range (Comer *et al*. 2013b, Figure 2) and Central Basin and Range (Comer *et al*. 2013a, Figure 4-30). We considered invasive grass cover to be similar to current conditions for Scenario I based on modeling presented in the BLM Rapid Ecoregion Rapid Assessment for 2025 (Comer *et al*. 2013b, Figure 2). Under a scenario of increased threats, Scenario II projects an increase in cover by augmenting the 2025 projections by the potential risk of invasion modeled in the same analysis to indicate areas where current levels were projected to increase in the future (Comer *et al*. 2013b, Figure 3). Areas with an invasion index value less than 0.5 have higher potential risk of invasion by invasive grasses and were assigned one category higher for invasive grass cover, than was assigned for the current condition (Figure 6-2; no/low risk, <5, 5-15, 15-25, 25-45 and >45 percent). Small decreases in the proportion of the analysis unit with no to low risk of invasive grasses occurred across all analysis units with the exception of YUJA East and the Hybrid Zone, which are anticipated to have similar cover in the future. Greater than 40 percent of the area in YUJA North and YUJA Central was modeled to increase in invasive grass cover from no to low risk to less than 5 percent invasive grass cover.

To model an increased risk of wildfire, we utilized the current model estimates from Klinger *et al*. (2021) to project the proportion of each analysis unit potentially impacted by higher natural ignition probability, higher frequency of wildfire, and higher burn severity (Table 6-1; Figure 6-4), which represents the best available information on current and future wildfire risk. However, Klinger *et al*. (2021) does not specifically address what portion of the Mojave Desert is likely to burn. To project the proportion of Joshua trees' distribution that may burn by the end of the century (2070–2099), we characterized the average acres burned within each analysis unit over the last 60 years (1960–2020; Table 8-4) (Cal Fire 2022, unpaginated; NIFC 2022, unpaginated). On average, 8 percent of the range of Joshua trees has burned, though there is variability across the analysis unit. Based on this estimate, we applied the current wildfire model results that are expected to be accurate for the next 30 to 50 years to Scenario I and forecasted a 50 percent increase in wildfires, or up to12 percent of the acreage currently occupied. Similarly, under Scenario II, we used the same framework and considered how climate change, particularly prolonged drought, may change vegetation dynamics and the risk of wildfire and projected that the area burned would double to approximately 18 percent of occupied habitat. At low elevations, a decreased risk is forecasted due to lower vegetation cover due to drought and a history of more frequent fires, though invasive grass cover and wildfire risk may increase substantial following high rainfall events as typically associated with El Niño-Southern oscillation. High wildfire risk is projected at middle and high elevations due to a drier fuel conditions, higher vegetative cover, the potential for invasive grasses to increase in cover including expanding their distribution to higher elevations, modeled higher burn severity, and the potential for large wildfires. There is uncertainty in where wildfires will occur in the future and the fire return interval; we projected wildfires to primarily occur in middle and high elevation vegetation communities based on the modeled wildfire risk, that includes habitat that could serve as climate refugia.

Table 8-4. Summary of the total acres burned and percent of the analysis unit burned from 1960 to 2020 (Cal Fire 2022, unpaginated; NIFC 2022, unpaginated).

Analysis Unit	Total Acres Burned	Percentage of the Analysis Unit Burned
YUBR North	38,921 (15,757)	2
YUBR South	195,108 (78,991)	9
YUJA North	503,853 (203,989)	24
YUJA Central	107,824 (43,653)	5
YUJA East	226 (92)	0
Grand Total	**845,932 (342,482)**	**9**

The potential effects of climate change include increased summer and winter temperatures and more variable precipitation, including extended droughts. The climate conditions modeled are based on an average across 13 GCMs from the CMIP 6 compiled in the ClimateNA tool and summarized in Figure 6-4 (version 7.21; Wang *et al*. 2016, unpaginated). Scenario I forecasts changes based on RCP 4.5 including an approximate 5.4° F (3° C) increase in the warmest month and coldest month of the year and the potential for more extreme warm temperatures. Annual precipitation is not forecasted to change substantially. There is some evidence of an increase in monsoonal precipitation compared to current conditions, that are more similar to what Joshua tree experienced historically. Overall, precipitation is anticipated to be more variable with periods of high precipitation generally followed by drought years and the potential for extended droughts, though there is a high degree of variability in future precipitation depending on the GCM. Scenario II forecasts future climate based on RCP 8.5 including more extreme warm weather conditions including an approximate 9° F (5° C) increase in temperature and the potential for more extreme warm weather events (Figure 6-4). There is also the potential for higher summer monsoonal rainfall compared to historical and current conditions, though overall drought conditions are forecasted to prevail based on increasing climate moisture deficits driven by warmer weather conditions.

To forecast the potential effects of future climate change discussed above on the distribution of Joshua trees, we evaluated results of the existing bioclimatic models that projected areas of climatically favorable (climatic refugia) and climatically unfavorable habitat (**section 6.4.4 Future Habitat Suitability**; Table 6-3; Appendix F). We did not develop an independent model but utilized the range of climatically favorable and unfavorable habitat modeled in these studies to describe Joshua tree habitat that may be occupied in the future. Overall, there is consensus that a large proportion of the distribution of Joshua trees is forecasted to be climatically unfavorable and unlikely to support suitable climatic conditions due to increased temperatures, decreased precipitation, or a general increase in drought stress in the future; though the different studies utilized different modeling methods, datasets, timeframes, and assumptions. Under a low emission scenario (Scenario I) approximating RCP 4.5 (A1B), several models predicted that approximately 60 to 80 percent of the range of Joshua trees would no longer be climatically favorable (Shafer *et al*. 2001, entire; Dole *et al*. 2003, entire; Cole *et al*. 2011, entire; Barrows and Murphy-Mariscal 2012, entire; Thomas *et al*. 2012, entire; Sweet *et al*. 2019, entire). Under a high emission scenario (Scenario II) approximately RCP 8.5 (A2), models predicted that 80 to 99 percent of the range of Joshua trees would no longer be climatically favorable (Barrows and Murphy-Mariscal 2012, entire; Thomas *et al*. 2012, entire; Comer *et al*. 2013b, entire; Sweet *et al*. 2019, entire).

Coarse scale climate modeling may not adequately capture microclimates (Nadeau *et al*. 2022, pp. 3229–3230) and studies using downscaled data identified the potential for climate refugia in topographically diverse areas including northerly aspects and steeper slopes (Barrows and Murphy-Mariscal 2012, p. 33; Sweet *et al*. 2019, p. 7). We lack downscaled modeling for the rest of Joshua trees' distribution outside of JTNP. Therefore, we considered that the remaining portion of Joshua trees' range that was considered climatically favorable could potentially serve as climate refugia (i.e., 60–80 percent is climatically unfavorable; therefore 20–40 percent is potentially suitable in Scenario I) where all the species needs will be met (e.g., sufficient pollinators, survival, and appropriate recruitment conditions to maintain population abundance); and that a greater proportion of climate refugia would likely occur in topographically diverse areas and at higher elevations and latitudes. Therefore, under a low emission scenario (Scenario I; RCP 4.5), we consider that approximately 40 percent of the habitat at higher elevations and latitudes may be suitable and serve as climate refugia, and that approximately 20 percent may serve as climate refugia at lower latitudes (Table 6-3). Under a high emission scenario (Scenario II; RCP 8.5), we consider that approximately 20 percent of the habitat at higher elevations and latitudes may be suitable and approximately 1 percent may serve as climate refugia at lower latitudes.

Although we can utilize the existing bioclimatic models to quantify the proportion of the range that may be climatically unfavorable at the end of the century, these projections are more uncertain the further out they project due to uncertainty of forecasted climate conditions and the potential species response. In particular there is a high degree of uncertainty in the species response to climatically unfavorable conditions at the end of the century, based on both the magnitude of the potential effects of the temperature increases and drought forecasted, and the timeframe over which individuals will be exposed to climatically unfavorable conditions. Joshua trees may experience reduced flowering, growth, and recruitment; increased mortality and risk of predation; and the potential for loss of occupied habitat and range contractions under unfavorable climatic conditions. There is more uncertainty the further into the future we project; therefore, the timing and magnitude of these responses are difficult to forecast at this time. It is not clear how and when Joshua tree individuals or populations may begin to respond to the effects of climatically unfavorable conditions including when recruitment may be reduced such that viability is reduced, how long adult trees may persist in climatically unfavorable conditions, and if there are physiological thresholds (Shafer *et al*. 2001, p. 207; Thomas 2022a, pers. comm.). Furthermore, the rate of warming and maximum exposure temperatures vary depending on the

RCP evaluated, contributing to further uncertainty the further into the future we project potential species effects (Knutti and Sedláček 2013, p. 370).

In light of these uncertainties, we do not project that all climatically unfavorable habitat will be devoid of Joshua trees at the end of the century. Instead, we forecast the potential for more detrimental effects with increasing magnitude of potential effects (e.g., temperature increases and drought stress), as well as, with increasing exposure or the timeframe where individuals are susceptible to climatically unfavorable habitat conditions. Therefore, we project that the species response will vary across the range of Joshua trees and be based largely on latitude, elevation, and wildfire history. For example, habitat at lower elevations are projected to experience higher magnitude impacts due to projected increases in temperatures and prolonged drought and these effects are expected to be of a higher magnitude at southern latitudes than more northerly latitudes. Similarly, the areas along the southern edge of the species' distribution are expected to be exposed to climatically unfavorable habitat conditions for a longer period as we project into the future, based on recent site-specific evidence of declines in survival, recruitment, and reproduction (Esque *et al*. 2010, p. 11; Barrows and Murphy-Mariscal 2012, p. 34; Cornett 2019, p. 9; Sweet *et al*. 2019, p. 7; Graver 2022, entire). Therefore, we project that due to the higher magnitude the threat of climate change and increased exposure to climatically unfavorable conditions at lower elevations and latitudes Joshua trees may experience more detrimental effects such as decreased habitat suitability including the loss of individuals, reduced recruitment, and the potential loss of occupied habitat in these areas. When evaluating the future conditions at the end of the century, we identified habitat areas where Joshua trees may no longer occupy a proportion of the modeled climatically unfavorable habitat resulting in the potential loss of occupied habitat or range contractions. These areas were generally defined as less than 3,937 ft (1,200 m) elevation, which delineates low elevation and middle elevation vegetation communities (Brooks and Matchett 2006, p. 153; Klinger *et al*. 2021, p. 3). Joshua trees may persist in areas of decreased habitat quality at slightly higher elevations and latitudes or in topographically diverse areas at lower elevation. At the end of the century, occupancy in marginal habitat areas may be maintained primarily through established trees and asexual reproduction, and recruitment is projected to be low to nonexistent. We project that the full effects of climate change may not be realized for many decades to hundreds of years, such that Joshua trees may continue to occupy habitat where all the species needs are no longer met, including areas that are functionally extirpated, though this will be difficult to assess in the near-term. All the species needs are anticipated to be met within climate refugia including similar tree densities and recruitment as current conditions. Most of the models described above project some degree of habitat expansion. However, given the limited dispersal of Joshua trees and uncertainty in the response of the yucca moths, we consider the potential for habitat expansion to be minimal without assisted migration. Therefore, we did not include potential habitat expansion in our estimates of Joshua trees future distribution described below and we forecast that any potential range expansion will not offset the large amount of acreage that are no longer climatically favorable.

Table 8-5. Future *Yucca brevifolia* and *Y. jaegeriana* occupied habitat within each analysis unit considering the cummulative effects of threats described for Scenario I and II.[1]

Analysis Unit	Current Distribution[1, 2]	Scenario I Climate Refugia[1, 2]	Scenario I Marginal Habitat[1, 2]	Scenario I Total Occupied Habitat[2]	Scenario I Percent Occupied Habitat Remaining	Scenario II Climate Refugia[1, 2]	Scenario II Marginal Habitat[1, 2]	Scenario II Total Occupied Habitat[2]	Scenario II Percent Occupied Habitat Remaining
YUBR North	2,129,113 (851,645)	650,000 (260,000)	600,000 (240,000)	1,250,000 (500,000)	59	300,000 (120,000)	800,000 (320,000)	1,100,000 (440,000)	52
YUBR South	2,288,162 (915,265)	350,000 (140,000)	600,000 (240,000)	950,000 (380,000)	42	20,000 (8,000)	650,000 (260,000)	670,000 (268,000)	29
YUBR Total	**4,417,276 (1,766,910)**	**1,000,000 (480,000)**	**1,200,000 (480,000)**	**2,200,000 (880,000)**	**50**	**320,000 (128,000)**	**1,450,000 (580,000)**	**1,770,000 (708,000)**	**40**
YUJA North	2,065,476 (826,191)	700,000 (240,000)	600,000 (240,000)	1,300,000 (520,000)	63	300,000 (120,000)	750,000 (300,000)	1,050,000 (420,000)	51
YUJA Central	2,089,163 (835,665)	700,000 (240,000)	600,000 (240,000)	1,300,000 (520,000)	62	300,000 (120,000)	625,000 (250,000)	925,000 (370,000)	44
YUJA East	754,821 (301,928)	100,000 (40,000)	250,000 (100,000)	350,000 (140,000)	46	8,000 (3,200)	300,000 (120,000)	308,000 (123,200)	41
YUJA Total	**4,909,460 (1,963,784)**	**1,500,000 (600,000)**	**1,450,000 (580,000)**	**2,950,000 (1,180,000)**	**60**	**608,000 (243,200)**	**1,675,000 (670,000)**	**2,283,000 (913,200)**	**47**

[1] Forecasted estimates include areas of modeled climate refugia where species needs are expected to continue to be met and climatically unfavorable habitat of marginal quality that may include reduced tree densities and recruitment. This analysis assumes that the remaining portion of the current distribution may be largely unoccupied at lower elevations and latitudes.
[2] ac (ha).

We have similar uncertainties regarding the response of the yucca moth to modeled climatically unfavorable habitat conditions. We project that habitat suitability for the obligate moth pollinators will vary and will likely follow Joshua tree flowering events, though we have limited information on how their populations and range might change under future climate change. We forecast that yucca moths will persist in currently occupied climate refugia and that they may not occur or may occur in lower abundance in marginal habitat. We also lack information on how the rodent populations might vary under the different climate scenarios and project that predation will continue to be high under drought conditions.

8.2 Scenario I- *Yucca brevifolia*

Scenario I is based on a continuation of the magnitude of the current threats to *Yucca brevifolia* for habitat loss (land use), climate conditions, climate models, invasive annual grasses, and increased risk of wildfire following the resources and analysis described above. Given the wide range of *Y. brevilfolia*'s distribution there are differences in the direction and magnitude of threats which is summarized by analysis unit below along with the potential impacts to population resiliency

8.2.1 Population Resiliency

Yucca brevifolia population resiliency was evaluated under Scenario I for YUBR North and YUBR South.

8.2.1.1 YUBR North

At the end of the century under Scenario I, the overall resiliency of YUBR North is forecasted to be moderate to high and reduced relative to current conditions (Table 8-6). The analysis unit will continue to be occupied across a large and diverse area of approximately 1.3-million ac (500,000 ha; Table 8-4) of which 650,000 ac (260,000 ha) is forecasted to serve as climate refugia (Table 8-4). Bioclimatic models project that 60 to 70 percent of the analysis unit will no longer provide climatically favorable habitat for *Yucca brevifolia* due to increased summer and winter temperatures and increased drought stress (Table 6-3). We project that the species will continue to occupy mid- to high-elevation zones and higher latitudes identified as climatically unfavorable in the models because either the magnitude of the effects of climate change or the exposure timeframe are reduced, though demography metrics are projected to be lower than current conditions. Reduced habitat quality including the potential for tree mortality, reduced tree densities, and limited recruitment are projected to occur throughout areas of climatically unfavorable habitat and is projected to be worse at the lower elevations and latitudes due to both climate change and the negative feedback of drought on herbivory and wildfire. The remaining approximately 30 to 40 percent of YUBR North is projected to be suitable in climate refugia at middle and high elevations and we project abundance and recruitment in these areas to be similar to current conditions. Climate refugia occurs within middle and high elevation vegetation communities that are modeled to have high burn severity. Although the probability of natural ignitions is low, this analysis unit is forecasted to have uncommon, large wildfire events. We forecast large portions of the climate refugia to remain suitable and that large fire events may impact approximately 180,00 ac (7,284 ha) by the end of the century. Based on moderate burn severity, we project that a large portion of the trees will die over time including younger age-classes and clones produced from stressed or dying adult trees, and mortality will be exacerbated due to subsequent drought conditions. Wildfires also impact nurse shrubs and the surrounding vegetation; and we project that portions of the area forecasted to burn may recover after fire due to lower estimated fire frequency, though, some areas may take longer than 80 to 100 years to recover post-fire. During the recovery period, some areas will not support recruitment due to the lack of nurse plants or Joshua tree propagules particularly in large and high severity burns. Based on the threats described above, we project that average tree density in the remaining occupied habitat will be slightly reduced across the analysis unit; but will remain in moderate to high condition given the potential for higher tree density at cooler, high elevation locations. Recruitment, in terms of the percentage of juveniles on the landscape, is anticipated to decrease at lower elevations and in areas burned by wildfire. Although it is unclear what level of recruitment is necessary to sustain populations in the future due to the species long lifespan, highly variable recruitment, and low establishment rates relative to seed production. In total approximately 60 to 70 percent of the analysis unit is projected to continue to be occupied in climatically unfavorable or marginal habitat at middle elevations and within climatically favorable habitat in climate refugia, including Federal and NPS lands to the north. We do not forecast that projected increases in habitat loss due to development and renewable energy development will substantially further reduce the acreage of occupied habitat because the majority of development is anticipated to occur at lower elevations and flatter terrain that overlaps with habitat areas that are projected to no longer be suitable or contain *Yucca brevifolia* due to the potential loss of occupied habitat. The northern portion of the analysis unit includes areas at high risk of invasive grasses and habitat quality is moderate to high overall. Despite the increase in current threats describe above, YUBR North is projected to have high resiliency under Scenario I, though reduced compared to current conditions.

8.2.1.2 YUBR South

YUBR South is forecasted to have the greatest potential loss of occupied habitat within the distribution of *Yucca brevifolia*; but is projected to maintain moderate to high population resiliency (Table 8-6) across approximately 950,000 ac (380,000 ha; Table 8-4) of occupied habitat including 350,000 ac (140,000 ha) forecasted to serve as climate refugia where all the species needs are projected to be met (Table 8-4). The southern portion of *Y. brevifolia*'s distribution is forecasted to be climatically unfavorable; approximately 80 percent of the distribution is projected to provide marginal habitat or may be unlikely to support Joshua trees or recruitment habitat, particularly at lower elevations. We anticipate that these areas may experience drought-exacerbated predation events during extreme dry periods increasing the potential for tree mortality and the loss of occupied habitat. The magnitude of these threats may be temporarily alleviated to some degree during periods of higher rainfall but these events are projected to be infrequent. Climate refugia are anticipated to be maintained at higher elevations, on steep slopes and northern exposures including up to 20 percent of the analytical unit. Potential climate refugia occurs within middle and high elevation vegetation communities characterized by infrequent wildfires of high severity and up to 12 percent of the climate refugia may burn before the end of the century. Moderate to high severity wildfires at higher elevation may result in tree mortality, reduced densities, and higher mortality of individuals at younger age-classes. We also project a high degree of resprouting and that post-fire recovery times may be longer than 80 to 100 years and will be exacerbated by drought conditions. We forecast that a portion of the trees will die over time due to burn damage and charring, including clones produced from stressed or dying adult trees. Wildfires also impact nurse shrubs and the surrounding vegetation; therefore, we project the burned habitat will be potentially unsuitable for recruitment until the habitat recovers. At lower elevations, high periodic rainfall may increase invasive grass cover and risk of fire temporarily, but we expect drought conditions to prevail and wildfires to be infrequent by the end of the century due to reduced vegetative cover overall. Similar to YUBR North, natural ignition probability and fire frequency is estimated to be low across the analysis unit, though an increased risk of human cause fires is anticipated near urban centers and in areas with high recreation use. Land use projections indicate that development will be focused in areas that correspond with projected loss of occupied habitat and will total approximately 480,000 ac (194, 249 ha) including potential renewable energy development [250,454 ac (101,355ha)]. We project that development will largely occur near existing urban centers at low elevation in areas that are projected to no longer be suitable and unlikely to support *Y. brevifolia* in the future. Thus, we do not forecast development to substantially increase the loss of occupied habitat beyond that described for climate change above. Projected future development is concentrated in the southern portion of YUBR South on both private and federally owned lands.

In total, approximately 42 percent of the analysis unit is projected to continue to be occupied in climatically unfavorable, marginal habitat, and climatically favorable habitat within climate refugia, much of which is on Federal lands, including habitat protected by the NPS. Tree densities and recruitment in climate refugia may be reduced due to drought conditions and in the areas projected to burn though it is unclear what level of recruitment is necessary to sustain populations in the future due to the species long lifespan, highly variable recruitment, and low establishment rates relative to seed production. Habitat quality with respect to invasive grass cover is forecasted to maintain high quality due to the large portion of the analysis unit with no to low risk of invasive grasses, despite periods of higher cover following extreme rainfall events that promote invasive grass cover. Overall YUBR South is projected to be moderate to highly resilient in the future and reduced compared to current conditions despite the potential loss of occupied habitat and range contractions, limited wildfires in climate refugia, and increased development pressure.

8.2.2 Redundancy

Under Scenario I, we consider *Yucca brevifolia* to have decreased redundancy to withstand catastrophic events relative to current conditions but will continue to occupy a large and ecological diverse area. Although YUBR South has lower resiliency, the species is projected to occupy approximately 2.2-million ac (880,000 ha) in the future, though a portion of that habitat may be of marginal suitability due to the effects of climate change and wildfire. The majority of the remaining habitat is forecasted to be conserved or occur on Federal lands with some degree of regulatory protection, management, and/or reduced probability of anthropogenic disturbance. Private lands within the range of *Y. brevifolia* tend to occur at lower latitudes and elevations anticipated to be of marginal habitat quality or potential unoccupied at the end of the century; therefore, development of these areas is not anticipated to impact substantial areas of suitable habitat or reduce redundancy. Despite the reductions in the acreage of occupied habitat, potential adverse impacts due to catastrophic events, such as wildfire, prolonged drought and severe predation events, are unlikely to extirpate an entire analysis unit or the species.

Table 8-6. Scenario I condition categories and population resiliency by analysis unit.

Condition	Quantity of Occupied Habitat	Invasive Grass Cover	Abundance	Recruitment	Total Score
YUBR North	Moderate	Moderate To High	Moderate To High	Moderate To High	Moderate To High (3.8)
YUBR South	Moderate	High	Moderate	Moderate	Moderate To High (3.5)
YUJA North	Moderate	Low To Moderate	Low	Low	Low To Moderate (1.8)
YUJA Central	Moderate	Moderate	Low To Moderate	Low To Moderate	Moderate (2.5)
YUJA East	Low	Moderate	Low	Low	Low (1.5)
Hybrid Zone	Low	Moderate	NA	NA	Low To Moderate (2.0)

8.2.3 Representation

Representation, as measured by ecological diversity of Yucca brevifolia habitat, is reduced under Scenario I relative to current conditions. The two analysis units will continue to occupy highly diverse areas within the Mojave and Great Basin Deserts, though portions of the ecoregions at lower elevation may no longer be suitable or occupied. The large area that the species occupies, the broad latitudinal gradient, and lack of habitat specialization promotes higher adaptive capacity; though we project the loss of occupied habitat and potential range contractions will have moderate reductions in the ecological variability and number of ecoregions occupied in both YUBR North and YUBR South. The life history factors that promote persistence, such as clonal growth, are anticipated to maintain individuals across a large portion of the current distribution.

However, there is the potential for the loss of genetic variability at the southern limit of the species range due to the effects of climate change. Potentially important genotypes adapted for arid conditions may die or no longer reproduce should climatic conditions restrict flowering and recruitment. We also forecast representation to decline as northern latitudes become warmer and those genotypes may not be as well adapted to changing conditions. The species' adaptive capacity is also constrained by its obligate mutualism with the yucca moth and it is not clear how the moth will respond. We forecast that yucca moth populations may be maintained in areas where the Joshua trees persist and may be substantially reduced in habitat with marginal suitability, though there is a high degree of uncertainty with this assumption. We project that there will be limited opportunities for range expansion under Scenario I and we forecast that the acreage of potential habitat expansion will not substantially offset the amount of occupied habitat that is projected to be marginal or no longer suitable. Therefore, *Yucca brevifolia* is projected to have reduced representation that may impact the ability of the species to adapt to environmental conditions over time.

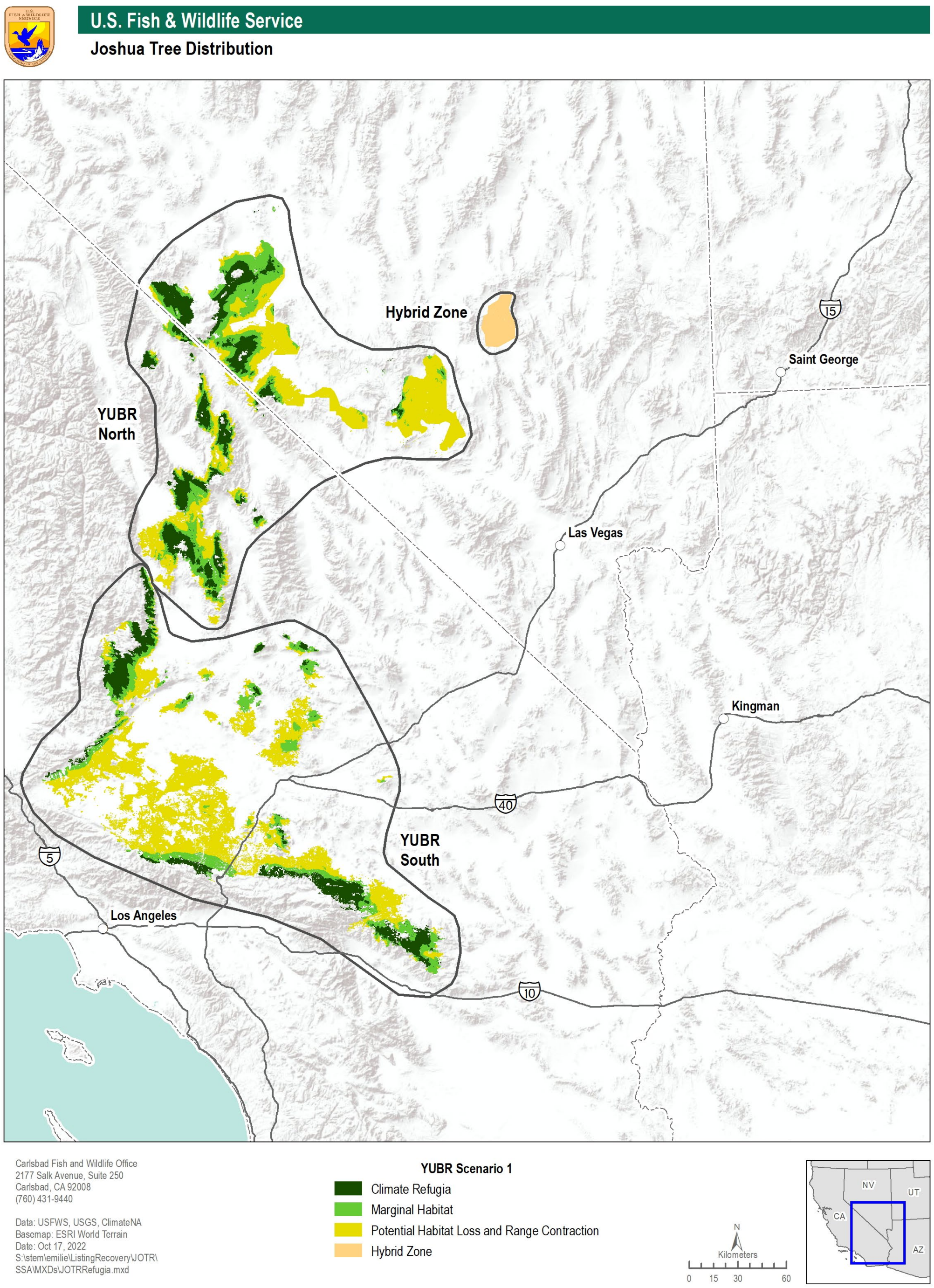

Figure 8-3. Graphical representation of projected areas of *Yucca brevifolia* occupied habitat (climate refugia and marginal habitat) and areas of potential loss of occupied habitat and range contraction under Scenario I.

8.3 Scenario I - *Yucca jaegeriana*

Scenario I is based on a continuation of the magnitude of the current threats to *Yucca jaegeriana* for habitat loss (land use), climate conditions, climate models, invasive annual grasses, and increased risk of wildfire, following the resources and analysis described above. Given the wide range of *Y. jaegeriana* distribution there are differences in the direction and magnitude of threats which is summarized by analysis unit below along with the potential impacts to population resiliency.

8.3.1 Population Resiliency

Yucca jaegeriana population resiliency was evaluated under Scenario I for YUJA North, YUJA Central, and YUJA East.

8.3.1.1 YUJA North

Under Scenario I, YUJA North is forecasted to have low to moderate population resiliency due to habitat degradation and potential loss of occupied habitat associated with climate change and the high risk of wildfire currently and in the future (Table 8-6). Although YUJA North occurs toward the northern limit of *Yucca jaegeriana* distribution, more than half of the analysis unit occurs at lower elevations that are projected to be climatically unfavorable. Climate models project that approximately 60 percent of the analysis unit will be climatically unfavorable, or the habitat will experience varying degrees of degradation including tree mortality, decreased tree densities, and decreased recruitment. Climate refugia is anticipated to sustain similar densities and recruitment within approximately 40 percent of the current distribution; however climate refugia occurs at middle and high elevation vegetation communities that are modeled to have high burn severity and higher fire frequency. Approximately 12 percent of modeled climate refugia is forecasted to be impacted by wildfire, including increased adult tree, juvenile, and seedling mortality, and a period of limited to no recruitment as the nurse plants and vegetation community recover. At lower elevations the increased risk and frequency of wildfire is projected to further reduce tree densities in areas affected by climate change and the frequency of fire may be sufficiently high to limit recruitment. Projections for future development are limited in YUJA North and are not anticipated to substantially further reduce the acreage of occupied habitat.

Up to 1.3 million ac (520,000 ha), representing 63 percent of the current acreage of the analysis unit, are likely to be occupied in the future, including 700,000 ac (280,000 ha) forecasted to serve as climate refugia where all the species needs are projected to be met (Table 8-4). The majority of the remaining occupied habitat is forecasted to be conserved or to occur on Federal lands with some degree of regulatory protection, management, and/or reduced probability of anthropogenic disturbance. The analysis unit is projected to be have low to moderate population resiliency because of the high proportion of the analysis unit characterized by high cover of invasive grasses and high fire frequency. The demographic parameters of abundance and recruitment are projected to be lower than current conditions, especially at lower elevations, and low condition overall, though it is unclear what level of recruitment is necessary to sustain populations in the future due to the species long lifespan, highly variable recruitment, and low establishment rates relative to seed production. Overall YUJA North is projected to be low to moderately resilient in the future due to the potential loss of occupied habitat due to climatically unfavorable conditions, increased wildfires at low elevation, and the risk of high severity wildfires in areas identified as climate refugia and a moderate amount of occupied habitat is forecasted to remain and is likely to be conserved.

8.3.1.2 YUJA Central

YUJA Central is forecasted to have moderate population resiliency due to habitat degradation and the potential loss of occupied habitat associated with climate change and the high risk of wildfire (Table 8-6). We project that 70 to 80 percent of the analysis unit will be climatically unfavorable or of marginal habitat quality due to future climate conditions, with the potential for increased tree mortality, reduced tree densities, and reduced recruitment. We project habitat suitability at low elevations may be marginal due to an increased probability of natural wildfire ignitions, higher frequency of wildfires, and drought-exacerbated predation resulting in further decreases in demographic parameters. *Yucca jaegeriana* is forecasted to persist within 20 to 30 percent of the analysis unit projected to provide climate refugia at middle and high elevations where all the species needs are projected to be met; however, these areas are modeled to have higher burn severity, the potential for more frequent wildfires, and the potential for delayed habitat recovery due to drought conditions. We forecast that up to 175,000 ac (70,820 ha) could potentially burn by the end of the century. However, approximately 1.3-million ac (520,000 ha) is projected to be occupied in the future, similar to YUJA North, including approximately 700,000 ac (280,000 ha) forecasted to serve as climate refugia and the remaining habitat may be of marginal habitat quality (Table 8-4). As a result, all demographic parameters are reduced and considered to be low to moderate condition in the future. Higher resiliency is projected in YUJA North, though it is unclear what level of recruitment is necessary to sustain populations in the future. We also forecast that habitat conditions will be moderate and reduced relative to current conditions due to an increase in invasive grass cover associated with increased frequency of fire. Overall YUJA Central is projected to be moderately resilient in the future, despite the potential for the loss of occupied habitat and range contractions, increased wildfires at low elevation, and increased risk of high severity wildfires in climate refugia, including a high proportion that is likely to be considered at reduced risk of anthropogenic disturbance.

8.3.1.3 YUJA East

YUJA East occurs at lower latitudes and experiences the most drought stress of any of the *Yucca jaegeriana* analysis units both currently and historically; and these conditions are projected to be exacerbated under future climate change resulting in low population resiliency (Table 8-6). YUJA East is forecasted to have the greatest potential loss of occupied habitat within the distribution of *Y. jaegeriana*. Approximately 350,000 ac (140,000 ha; Table 8-4) of occupied habitat is anticipated to persist at the end of the century, of which 100,000 ac (40,000 ha) is forecasted to serve as climate refugia where all the species needs are projected to be met (Table 8-4). Approximately 80 percent of the analysis unit is projected to be climatically unfavorable with a high probability of dead trees, reduce tree densities, and reduced recruitment due to drought conditions and severe predation events. Winter temperatures in YUJA East are projected to be warmer than 50° F (10° C), as a result seedling growth and establishment may be reduced. We project abundance and recruitment to be low, though it is unclear what level of recruitment is necessary to sustain populations in the future due to the species long lifespan, highly variable recruitment, and low establishment rates relative to seed production. Climate refugia are forecasted to persist in roughly 20 percent of the analysis unit, but that includes habitat at low elevation and less than 2 percent of the area is characterized as middle elevation vegetation. The lack of topography and higher elevation habitat areas limit the potential area of functional refugia. Compared to the rest of the range of *Y. jaegeriana*, YUJA East is characterized by lower risk of wildfires, including low wildfire frequency, probability of natural ignitions, and burn severity. If wildfires occur at lower elevation, the habitat is unlikely to recover due to the exacerbating effects of drought. The highest increase in development is projected in YUJA East, but the acreage forecasted to be developed is small relative to the size of the analysis unit and is not anticipated to substantially reduce the acreage of occupied habitat. We lack information on invasive grass cover for the entire analysis unit; but the area modeled is characterized as no to low cover by invasive grasses. Therefore, we do not project additional habitat loss and degradation beyond the effects of drought and increasing temperatures which contribute to reduce population resiliency and low condition overall. A small proportion of the range is conserved and a high proportion of the remaining habitat occurs on Federal land and is unlikely to be developed in the future.

8.3.2 Redundancy

Yucca jaegeriana is forecasted to occur across a large and diverse area of approximately 2.9 million ac (1.2-million ha) across three analysis units (YUJA Central, YUJA North, and YUJA East), including 1.5 million acres (600,000 ha) forecasted to serve as climate refugia (Table 8-4). Although we anticipate reductions in resiliency under Scenario I for all analysis units, we project that all analysis units will persist into the future under catastrophic events such as wildfire, extended drought, and severe herbivory events, though YUJA East is more vulnerable. Periods of infrequent, higher rainfall are projected to temporarily ameliorate drought stress and relax predation pressure such that trees continue to occupy a large area spread over several states, though at reduced tree densities. Additionally, plants are located primarily on Federal and State lands with less anthropogenic disturbance and where planning and regulations support the protection and conservation of Joshua trees. We forecast that there will be limited opportunities for range expansion under Scenario I without assisted migration but it will not offset the large amount of acreage that are no longer suitable or of marginal quality. Due to the uncertainty regarding dispersal and yucca moth populations, potential habitat expansion was not included in our forecasts of future occupied habitat.

8.3.3 Representation

Representation, as measured by ecological diversity, is reduced relative to current conditions, and the three analysis units are projected to continue to occupy diverse areas within the Mojave, Great Basin, and Sonoran Deserts. *Yucca jaegeriana* is projected to occupy a number of ecoregions though the range is generally less ecologically diverse than *Y. brevifolia*. The relatively large area that the species occupies, the broad latitudinal distribution, and lack of habitat specialization promote adaptive capacity. However, portions of ecoregions a lower latitudes and elevations may no longer be occupied though clonal sprouts may allow the species to persist in areas of marginal suitability. The assessment of population resiliency highlighted the potential for reduced population densities and recruitment, particularly in the southern portion of the species' range, and the potential for loss of genetic variability that may decrease the representation of the species as a whole. We also forecast representation to decline as northern latitudes become warmer and those genotypes may not be as well adapted to changing conditions. Adaptive capacity is also constrained by its obligate mutualism with the yucca moth and it is not clear how the moth will respond. We forecast that the yucca moth populations will be maintained in areas where the Joshua trees persist and continue to flower in climate refugia and that their populations may be reduced or extirpated in areas of marginal habitat quality and in areas of potential range contraction. Therefore, *Y. jaegeriana* is considered to have reduced representation that may impact the ability of the species to adapt to environmental conditions over time.

8.4 Scenario I - Hybrid Zone

The Hybrid Zone analysis unit is projected to be distributed across a small acreage of occupied habitat. It is characterized as low condition due to habitat quantity, though it occurs adjacent to both *Yucca brevifolia* and *Y. jaegeriana* occupied habitat. The Hybrid Zone is located on the upper latitude limit of Joshua tree's distribution; therefore, we anticipate reduced effects of climate change and the potential for small areas of habitat expansion, though potential habitat expansion is not expected to substantially offset declines in other analysis units. Approximately 70,000 ac (28,000 ha) is anticipated to be occupied in the future. We forecast minimal reductions in abundance and recruitment. High invasive grass cover will continue to occupy a larger portion of the analysis unit (32 percent) and the analysis unit is characterized by infrequent, high severity wildfires in areas likely to support climate refugia. In burned areas we project some tree mortality with higher mortality of individuals at younger age-classes, and the time until habitat recovery may be longer, particularly under drought conditions. We also project sprouting post-fire and higher clonal survival at middle and high elevations. Urbanization and renewable energy development are not forecasted to contribute toward substantial loss of occupied habitat. Hybrid Joshua trees have reduced fitness (Smith 2022, pers. comm.); as hybridization increases there is the potential for reduced reproductive output and tree density, though we do not have information to quantify the effects. We project that these potential effects will be minimal and consider future representation and redundancy in the Hybrid Zone will be reduced relative to current conditions.

8.5 Scenario II- *Yucca brevifolia*

Scenario II is based on an increase in the magnitude of the current threats to *Yucca brevifolia* for habitat loss (land use), climate conditions, climate models, invasive annual grasses, and increased risk of wildfire. The analysis is based on RCP 8.5 when that data was available. The threat of invasive grasses increased in magnitude by adjusting the modeling results presented in the section on factors influencing viability analysis by the modeled risk of invasiveness (Comer *et al*. 2013b, Figure 3). Given the wide range of Joshua tree's distribution there are differences in the magnitude of threats, which is summarized by analysis unit, along with the potential impacts to population resiliency.

8.5.1 Population Resiliency

Yucca brevifolia population resiliency was evaluated under Scenario II for YUBR North and YUBR South.

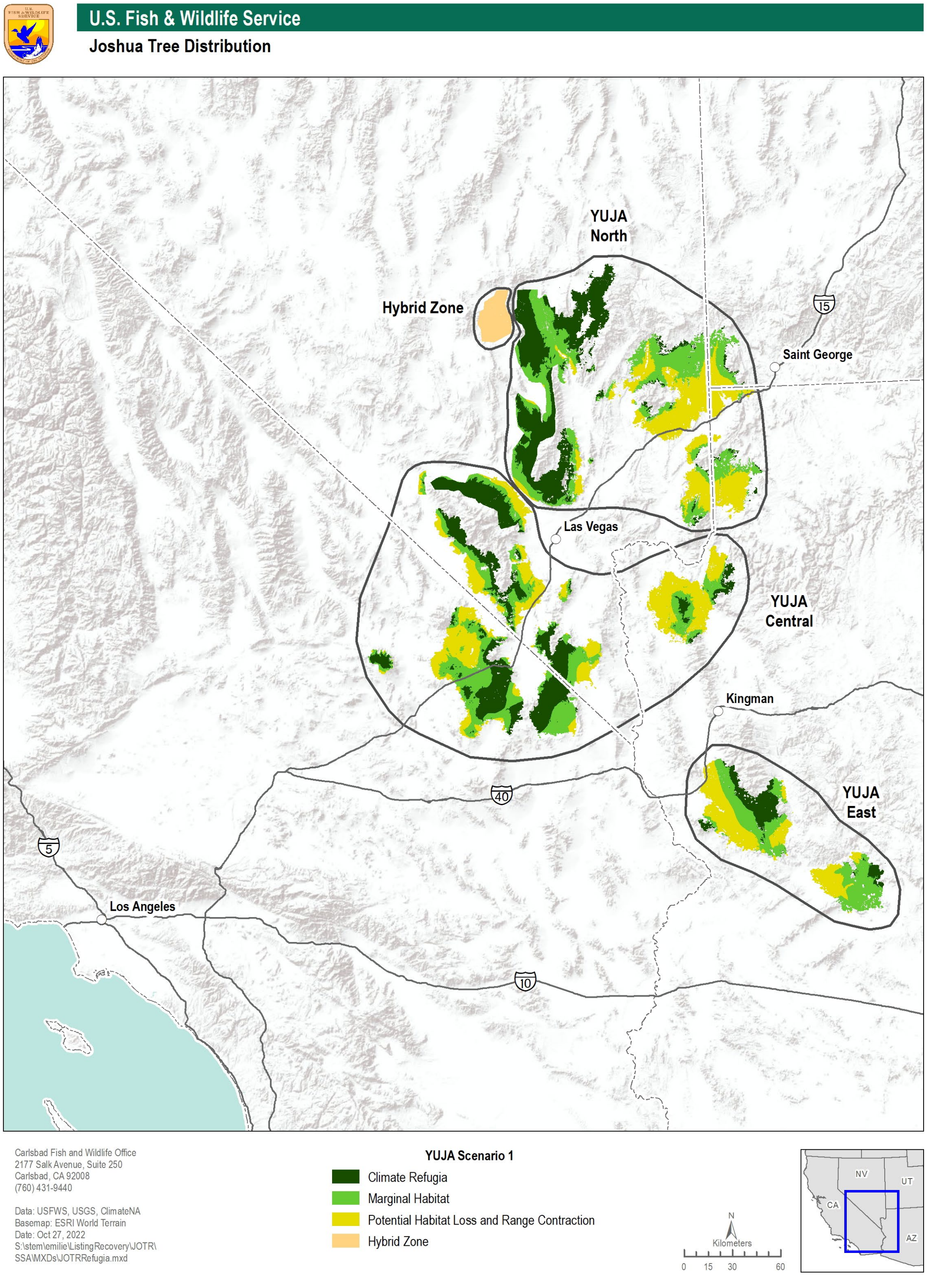

Figure 8-4. Graphical representation of projected areas of *Yucca jaegeriana* occupied habitat (climate refugia and marginal habitat) and potential loss of occupied habitat under Scenario I.

8.5.1.1 YUBR North

At the end of the century under Scenario II, the resiliency of YUBR North is forecasted to be moderate and decreased relative to Scenario I (Table 8-5) in the remaining approximately 1.1 million acres (440,000 ha) of occupied habitat, including 300,000 ac (120,000 ha) modeled as climate refugia where all the species needs are projected to be met (Table 8-4). We forecast that 80 percent of the analysis unit may no longer provide climatically favorable habitat for *Yucca brevifolia* due to increased summer and winter temperatures as well as increased drought stress. Tree mortality, reduced tree densities, and limited recruitment is anticipated to occur throughout areas of climatically unfavorable habitat and is projected to be worse at the lowest elevations due to both climate change and the potential for extreme herbivory events that contribute to potential loss of occupied habitat. Approximately 20 percent of YUBR North is projected to continue to be suitable in climate refugia at higher latitudes and elevations; we generally forecast that abundance and recruitment in these areas to be similar to current conditions. However, habitat at middle and high elevations are projected to have increased risk of high severity burns and we anticipate that the risk of wildfire will increases as woody biomass dries out as a result of the effects of climate change. Approximately half of the high elevation climate refugia has the potential to burn in infrequent high severity fires that may result in high tree mortality and habitat conversion, though these high magnitude events are anticipated to be infrequent. In burned areas, some mortality of adult trees and younger age-classes is projected resulting in reduced tree densities. Depending on the location and severity of the burn, Joshua trees may not recover for over 100 years, though nurse plants and the vegetation community may reach pre-burn conditions within one to several decades. Land use projections indicate a 1.2 percent increase in the acreage of occupied habitat developed and that does not substantially contribute to habitat loss compared to that forecasted under climate change and increased risk of wildfire. The occupied habitat remaining includes Federal and NPS lands to the north, though large areas of occupied habitat will likely be degraded toward the southern border of the analysis unit. We project slight increases in the cover of invasive grasses as areas that had no invasive grass cover are modeled to be invaded at low invasive grass cover, but the proportion of the analysis unit characterized by high invasive cover is the similar to Scenario I (13 percent). Based on the threats described above, we forecast that tree density will be reduced on average due to increasing drought conditions and wildfire; and will be moderate overall condition given the potential for areas of higher tree density within climate refugia. Recruitment, in terms of the percentage of juveniles on the landscape, is forecasted to decrease with the potential for no to limited recruitment in the remaining occupied habitat at lower elevations and following wildfires, though it is unclear what level of recruitment is necessary to sustain populations in the future.

8.5.1.2 YUBR South

YUBR South is forecasted to have the greatest potential loss in the acreage of occupied habitat within the distribution of *Yucca brevifolia* under Scenario II and is projected to have low to moderate population resiliency (Table 8-6). Approximately 670,000 ac (268,000 ha), of which 20,000 ac (8,000 ha) is forecasted to serve as climate refugia where all the species needs are projected to be met (Table 8-4). The southern portion of *Y. brevifolia*'s distribution is projected to be climatically unfavorable, with up to 99 percent of the habitat providing marginal habitat quality or unlikely to support Joshua trees or recruitment habitat, particularly at lower elevations.

These areas are projected to also be impacted by severe predation events during periods of drought, thus increasing the probability of tree mortality. Prolonged droughts are projected to limit the spread of invasive grasses, but nurse plants are also projected to die or have reduced cover under these extreme conditions with corresponding impacts on recruitment. Predation pressure is anticipated to be alleviated to some degree during periods of higher rainfall which also have the potential to increase invasive grass cover; but prolonged droughts are likely to prevail, and vegetation cover is projected to be reduced relative to current conditions and Scenario I. Climate refugia are anticipated to be maintained at higher elevations, on steep slopes and northern exposures, in areas also modeled to have high burn severity. We forecast as much as 18 percent of the remaining climate refugia may burn in infrequent, high severity wildfires including high tree mortality and prolonged habitat recovery that is projected to limit recruitment. Tree densities are forecasted to be low to moderate due to the combined effects of drought, predation, and wildfire, that is forecasted to occur at moderate and high elevation in climate refugia. Recruitment in climate refugia is forecasted to be low to moderate and reduced relative to current conditions and Scenario I, with no to minimal at lower elevations, though it is unclear what level of recruitment is necessary to sustain populations in the future due to the species long lifespan, highly variable recruitment, and low establishment rates relative to seed production. Land use projections indicate that development will impact approximately 290,000 ac (117,359 ha) of occupied habitat including portions of the analysis unit identified as climate refugia. Habitat quality with respect to invasive grasses is reduced and approximately 10 percent of the analysis unit is modeled to have increased invasive cover in areas where invasive grasses do not currently occur. These additional impacts are accounted for in occupied habitat forecasted to support *Y. brevifolia* in the future under Scenario II, much of which is projected to be conserved or occur on lands managed by the Federal government.

8.5.2 Redundancy

Under Scenario II, we consider *Yucca brevifolia* to have decreased redundancy due to the potential the loss of occupied habitat or range contractions. Although YUBR South has lower resiliency, the species is forecasted to occupy a large and diverse area of approximately 1.8 million ac (708 ha), including a portion that may be of marginal habitat quality. However, the species needs will continue to be met in climate refugia that is limited in comparison to current conditions and Scenario I [320,000 ac (126,000 ha)]. The majority of the remaining habitat is forecasted to occur on Federal lands with some degree of regulatory protection, management, and/or reduced probability of anthropogenic disturbance. Private lands within the range of *Y. brevifolia* tend to occur at lower latitude and elevation; and future development impacts are projected to occur in areas of where the loss of occupied habitat is forecasted due to the effects of climate change. Both of these pressures were considered in the redundancy evaluation and acreage described above. Despite the reductions in the acreage of occupied habitat and redundance, the potential adverse impacts due to catastrophic events, such as wildfire, prolonged drought, and severe predation events, are unlikely to extirpate an entire analysis unit or the species.

8.5.3 Representation

Representation, as measured by ecological diversity of *Yucca brevifolia* habitat, is reduced under Scenario II compared to current conditions and Scenario I. The two analysis units continue to occupy a diverse area within the Mojave and Great Basin Deserts. Portions of the ecoregions at lower elevation and along the southern limit of the species distribution may no longer be occupied due to climatically unfavorable conditions conferring reduced representation. The relatively large, albeit reduced, area that the species occupies, the broad distribution, and lack of habitat specialization confer some adaptive capacity. The life history factors that promote persistence, such as clonal growth, are anticipated to maintain individuals across approximately 40 percent of the species current distribution. There is a high a potential for the loss of genetic variability at the southern limit of the species range. Potentially important genotypes adapted for arid conditions may die or no longer reproduce should climatic conditions restrict flowering and recruitment as anticipated. We also project reductions in representation as northern latitudes become warmer and those genotypes may not be as well adapted to changing conditions. *Yucca brevifolia's* adaptive capacity is also constrained by its obligate mutualism with the yucca moth and it is not clear how the moth will respond, but we project the yucca moth populations to be maintained in areas where the Joshua trees persist and continue to flower in climate refugia and their populations may be limited elsewhere. We forecast that there will be limited opportunities for range expansion under Scenario II and we do not anticipate that expansion could offset the acreage that is no longer climatically favorable, of marginal habitat quality, or potentially no longer occupied. Therefore, *Y. brevifolia* is considered to have reduced representation that may impact the ability of the species to adapt to environmental conditions over time.

8.6 Scenario II - *Yucca jaegeriana*

Scenario II is based on an increase in the magnitude of the current threats to *Yucca jaegeriana* for habitat loss (land use), climate conditions, climate models, invasive annual grasses, and increased risk of wildfire. The analysis is based on RCP 8.5 when that data was available. The threat of invasive grasses increased in magnitude by adjusting the modeling results presented in the **Chapter 6 Factors Influencing Viability** by the modeled risk of invasiveness (Comer *et al* 2013b, Figure 3). Given the wide range of *Y. jaegeriana's* distribution there are differences in the direction and magnitude of threats, which is summarized by analysis unit along with the potential impacts to population resiliency (Table 8-5).

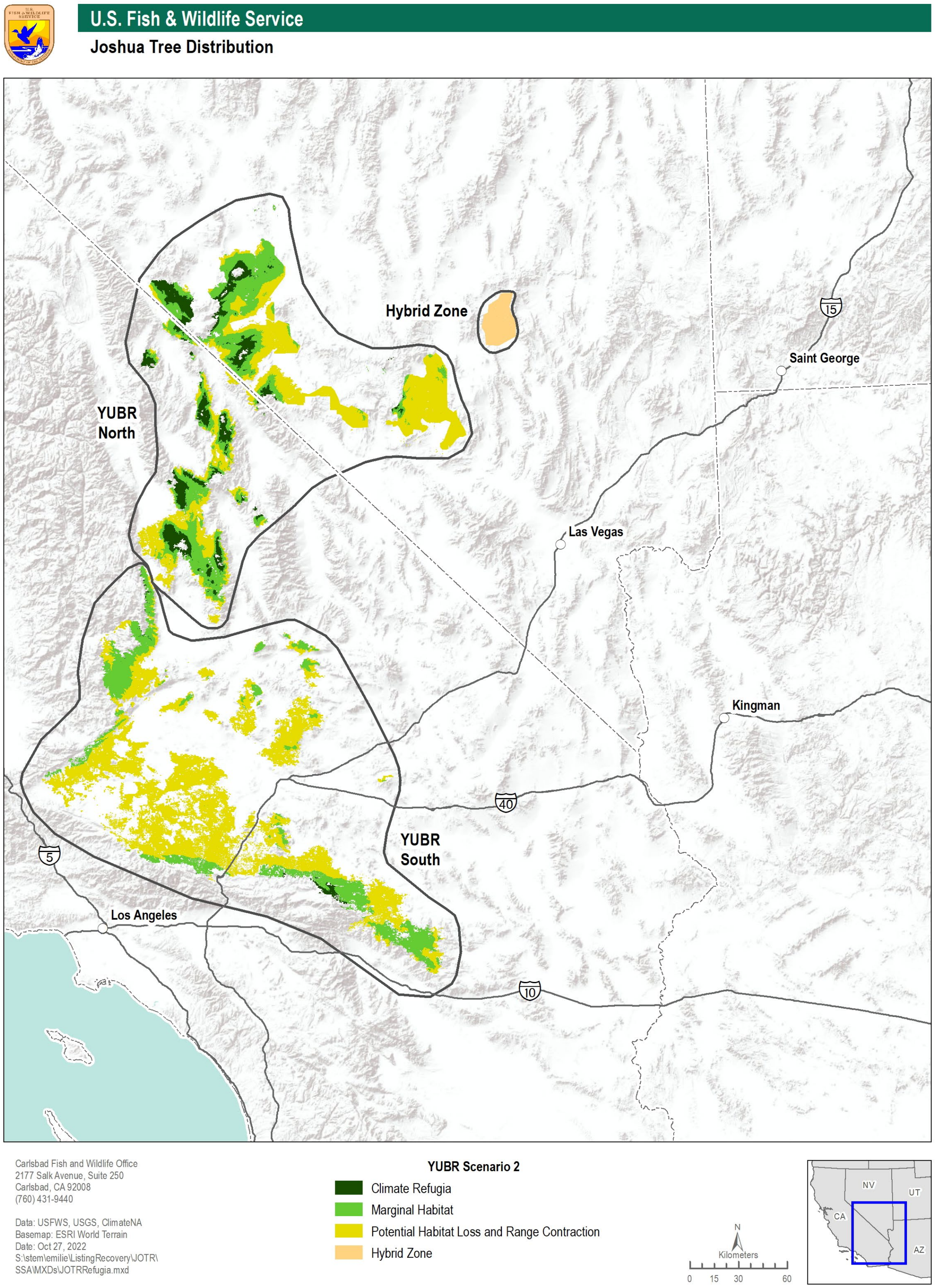

Figure 8-5. Graphical representation of projected areas of *Yucca brevifolia* occupied habitat (climate refugia and marginal habitat) and potential loss of occupied habitat under Scenario II.

Table 8-7. Scenario II condition categories and population resiliency by analysis unit.

Condition	Quantity of Occupied Habitat	Invasive Grass Cover	Abundance	Recruitment	Total Score
Yubr North	Moderate	Moderate	Moderate	Moderate	Moderate (3.0)
Yubr South	Low To Moderate	Moderate To High	Moderate	Low To Moderate	Low To Moderate (2.5)
Yuja North	Moderate	Low	Low	Low	Low (1.5)
Yuja Central	Moderate	Moderate	Low	Low	Low To Moderate (2.0)
Yuja East	Low	Moderate	Very Low To Low	Very Low To Low	Low (1.3)
Hybrid Zone	Very Low To Low	Moderate	NA	NA	Low (1.8)

8.6.1 Population Resiliency

We evaluated *Yucca jaegeriana* population resiliency under Scenario II for YUJA North, YUJA Central, and YUJA East.

8.6.1.1 YUJA North

Under Scenario II, YUJA North is forecasted to have low population resiliency (Table 8-5); and approximately 1 million ac (420,000 ha) are forecasted to be occupied in the future, including 300,000 ac (120,000 ha) in potential climate refugia where all the species needs are projected to continue to be met (Table 8-4). Approximately 80 percent of the current distribution will be climatically unfavorable, or the habitat will experience varying degrees of degradation including tree mortality, decreased recruitment, and the loss of occupied habitat. Climate refugia are anticipated to sustain species needs and similar densities and recruitment as current conditions, within approximately 20 percent of the current distribution. However, climate refugia at high and middle elevation plant communities are estimated to have increased risk of wildfire including high burn severity and we forecast the potential for increased frequencies as woody fuels dry out under projected climate change. We forecast patches of climate refugia to remain but burned areas are anticipated to have reduced tree densities, including younger age-classes, and limited recruitment. The potential for high frequency fires may further limit recruitment throughout the analysis unit, particularly at lower elevation. Development is unlikely to substantially decrease the acreage of occupied habitat. The majority of the remaining habitat is forecasted to occur on Federal lands with some degree of regulatory protection, management, and/or reduced probability of anthropogenic disturbance. The analysis unit is projected to be low condition for invasive grasses, because of the high proportion of the analysis unit characterized by high cover of invasive grasses and the potential for increasing invasive grass cover with increasing fire frequency. We project the condition of demographic parameters (i.e., abundance and recruitment) to decrease at lower elevations, and to continue to be low condition as was characterized currently and likely historically for this analysis unit. However, there is uncertainty in the level of recruitment is necessary to sustain populations in the future due to the species' long lifespan, highly variable recruitment, and low establishment rates relative to seed production. Although resiliency is forecasted to be low, a high proportion of the remaining occupied habitat is likely to be conserved or occur on Federal lands with a reduced risk of habitat alteration due to development.

8.6.1.2 YUJA Central

YUJA Central occurs at lower latitudes and elevation and is forecasted to be low to moderate resiliency in the future under Scenario II (Table 8-5). Approximately 925,000 ac (370,000 ha) is forecasted to be occupied at the end of the century, including 300,000 ac (250,000 ha) in climate refugia where the species needs are expected to continue to be met (Table 8-4). We forecast 80 to 90 percent of the analysis unit will be climatically unfavorable with potential reductions in habitat quality. The potential exists for increased tree mortality, the loss of occupied habitat, and range contractions that may be exacerbated by severe predation events during drought conditions, and limited to no recruitment is forecasted at lower elevations. As a result, all demographic parameters are forecasted to be low condition at the end of the century, though it is unclear what level of recruitment is necessary to sustain populations in the future. *Yucca jaegeriana* is forecasted to persist within 10 to 20 percent of the analysis unit in climate refugia; however, these high and middle elevation vegetation communities are characterized by an increasing risk of wildfire, particularly the potential for high severity burn and high frequency fires, with more arid conditions due to the effects of climate change. We also forecast habitat quality will be moderate based on the relatively high proportion of the analysis unit with no to low risk of invasive grasses, though invasive grass cover is anticipated to increase with increasing frequency of wildfires. In burned areas we project mortality of adult trees and younger age-classes, and that Joshua tree recovery may take 100 years or more, depending on the severity and size of the wildfire. Recruitment is projected to be limited at lower elevations due to climatic conditions, frequent fire, and the resulting decrease in the cover and availability of nurse plants. Although resiliency is reduced, we project that a large proportion of the remaining habitat will be conserved or occur on Federal lands with a reduced risk of further habitat loss.

8.6.1.3 YUJA East

YUJA East occurs in the southern distribution of *Yucca jaegeriana* and experiences the most drought stress of any of the analysis units currently and likely historically, and these conditions are projected to be exacerbated under Scenario II. Approximately 99 percent of the analysis unit is projected to be climatically unfavorable with a high probability that occupied habitat will be lost including the potential for range contractions, dead Joshua trees, and nurse plants due to drought conditions and severe predation events. Winter temperatures in YUJA East are projected to be warmer than 50° F (10° C), as a result seedling growth and establishment is forecasted to be reduced and recruitment is forecasted to be nonexistent to limited at lower elevations. Climate refugia are forecasted to persist in roughly 1 percent of the analysis unit, though there is very limited available habitat at higher elevations. We forecast low frequency and low severity fires due to low vegetative and invasive grass cover. In burned areas we project mortality of adult trees and younger age-classes that already are vulnerable due to extended drought conditions and that habitat recovery may take more than 100 years. We forecast approximately 308,000 ac (123,200 ha) will be occupied in the future, including 8,000 ac (3,200 ha) of modeled climate refugia where all the species needs will continue to be met (Table 8-4). As a result, we forecast that abundance and recruitment will be very low to low condition at the end of the century, though it is unclear what level of recruitment is necessary to sustain populations in the future. Within the range of *Y. jaegeriana*, there is a small increase in the projected acreage of development; but these projections are not anticipated to contribute to increased reductions in occupied habitat because they are forecasted to occur at low elevation in habitat areas that are likely to no longer be occupied. We lack information on invasive grass cover for the entire analysis unit; but the area modeled is characterized as no to low cover by invasive grasses and invasive grasses are projected to decrease in cover with extended drought conditions. In consideration of the threat of climate change and wildfire, we project YUJA East to have low resiliency at the end of the century.

8.6.2 Redundancy

Under Scenario II, *Yucca jaegeriana* is forecasted to have decreased redundancy compared to current conditions and Scenario I due to the potential loss of occupied habitat and range contractions. Despite the threats and potential range contraction described above, *Y. jaegeriana* is projected to occur across a large and diverse area of approximately 2.2 million acres (913,200 ha) at the end of the century and all three analysis units will continue to be occupied. Although resiliency is reduced under Scenario II, all analysis units are projected to persist into the future under catastrophic events such as wildfire, extended drought, and severe predation events. No analysis units are forecasted to be extirpated, though YUJA East is more vulnerable. Additionally, the remaining occupied habitat is projected to occur on Federal and State lands with a decreased risk of anthropogenic disturbance and habitat loss.

8.6.3 Representation

The range of *Yucca jaegeriana* is ecologically and topographically less diverse than the range of *Y. brevifolia.* Representation, as measured by ecological diversity of habitats, is reduced under Scenario II relative to current conditions and Scenario I, due to potential loss of occupied habitat and range contractions; and ecoregions along the southern limits may not be occupied at the end of the century. However, *Y. jaegeriana* still occupies a relatively large area and broad latitudinal distribution that confers adaptive capacity and representation. The life history factors that promote persistence, such as clonal growth, are anticipated to maintain individuals and populations across a portion of the current distribution, with the exception lower elevations and the southern limit of the species distribution that is forecasted to be potentially unoccupied.

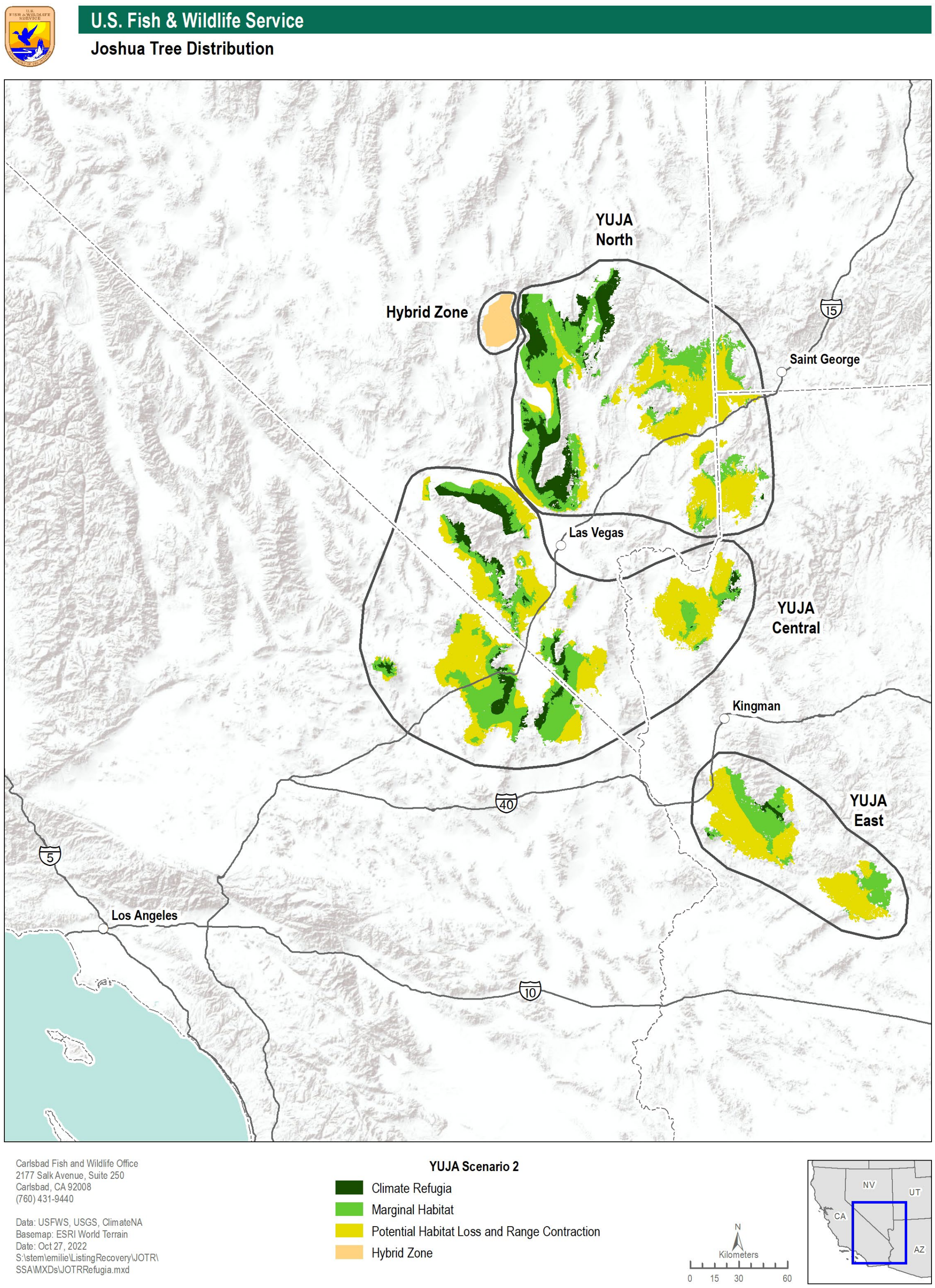

Figure 8-6. Graphical representation of projected areas of *Yucca jageriana* occupied habitat (climate refugia and marginal habitat) and potential loss of occupied habitat under Scenario II.

There is the potential for the loss of genetic variability and genotypes adapted to arid conditions in at lower elevations and latitudes that may reduce the representation of the species as a whole. We also project representation to decline as northern latitudes become warmer and those genotypes may not be as well adapted to changing conditions. Adaptive capacity is also constrained by its obligate mutualism with the yucca moth and it is not clear how the moth will respond; but we project the yucca moth populations will no longer occupy areas of the species distribution where flowering does not occur and will be largely limited to climate refugia. We forecast that there will be no to limited opportunities for range expansion under Scenario II. Therefore, *Yucca jaegeriana* is considered to have reduced representation that may impact the ability of the species to adapt to environmental conditions over time.

8.7 Scenario II - Hybrid Zone

The Hybrid Zone analysis unit is forecasted to be distributed across as little as 50,000 ac (20,234 ha) in the future and is characterized as low resiliency, though it contributes to the redundancy and representation of *Yucca brevifolia* to the west and *Y. jaegeriana* to the east. The Hybrid Zone is located on the upper latitude limit of Joshua tree's distribution; therefore, we anticipate reduced effects of climate change and the potential for small areas of habitat expansion at higher elevations, though potential range expansions are not expected to offset the significant loss of occupied habitat and range contractions projected. We forecast reductions in abundance and recruitment as a result of increasing temperatures and drought conditions. These climate conditions are projected to exacerbate the risk of fire in an area currently characterized by high burn severity. We project the potential for increased tree mortality, decreased tree density, and reductions in recruitment. Wildfires are not projected to be frequent, allowing the potential for habitat to recover between wildfires, though recovery is anticipated to be delayed due to drought conditions and may take as much as 100 years. High invasive grass cover will continue across a large portion of the analysis unit (32 percent) decreasing habitat quality. We do not forecast substantially habitat loss from development or renewable energy development. Hybrid Joshua trees have reduced fitness (Smith 2022, pers. comm.); if hybridization increases there is the potential for reduced reproductive output and tree densities, though the extent cannot be quantified at this time. But we have no information to suggest that representation and redundancy will decrease in the Hybrid Zone relative to current conditions.

CHAPTER 9. OVERALL SYNTHESIS AND SPECIES VIABILITY ANALYSIS

This SSA for Joshua trees summarizes the current conditions and a range of plausible future scenarios describing threats that we considered likely at the end of the century. The results describe a range of possible conditions for each of the Joshua tree analysis units and their projected future resiliency under these conditions (Table 9-1). In consideration of forecasted conditions, we evaluated resiliency, redundancy, and representation to describe the future species viability of *Yucca brevifolia* and *Y. jaegeriana*. In summarizing this information, we did not include the Hybrid Zone in our synthesis for either species, though we recognize that it confers redundancy and representation to both species. The Hybrid Zone is a small area at higher latitudes, is not projected to have substantial reductions in resiliency, redundancy, or representation, nor substantial improve or decrease viability of either species in the long term.

We had three significant obstacles to evaluating the species' viability and likelihood to persist for the next 80 years. We lack range-wide demographic data and an understanding of the amount and frequency of recruitment required to maintain population abundance given the species long lifespan. We can estimate how viability is likely to change given our assumptions. However, how viable the species is currently depends on how resilient the populations are, which is based in large part on their range-wide abundance and recruitment; values we cannot currently estimate. Similarly, there is uncertainty in magnitude and timing of future temperature increases and drought stress; and it is unclear when Joshua trees will begin to experience declines in survival and recruitment in response to unfavorable climate conditions. We also lack information on the population dynamics and environmental thresholds for the yucca moth species. For purposes of this SSA, we presume that the yucca moth populations will track Joshua tree flowering and will persist in climate refugia. We project they will experience similar habitat degradation, loss of occupied habitat, and range contractions as projected for Joshua trees, though there is a high degree of uncertainty regarding these assumptions.

9.1 *Yucca brevifolia*

Currently, we consider *Yucca brevifolia* viable and we forecast that viability will be reduced by the end of the century depending on the scenario. The species' current distribution is large [approximately 4.4-million ac (1.7-million ha)], occupies a diverse region of topographic and ecological diversity, and spans a large latitudinal gradient of approximately 300 mi (483 km) including potentially millions of individual trees and clones that confer both redundancy and representation. Currently, we consider total abundance across the species' range to be high and we presume occupancy throughout based on the current distribution prepared by USGS, though tree densities vary, and recruitment may already be limited in the southern portion of the range. Population resiliency is currently high in the YUBR North and YUBR South analysis units, based on the current low to moderate level of threat. There is currently evidence of drought stress at lower latitudes and elevations due to rising temperatures and drought conditions resulting in decreased tree vigor, mortality, and reduced recruitment. Under these particularly arid conditions, wildlife forage on *Y. brevifolia* throughout its range as a source of water and food often resulting in the death of trees, though we lack information on how prevalent these extreme predation events are occurring currently, as well as historically.

We evaluated potential threats to *Yucca brevifolia* now and in the future, including habitat loss due to urbanization, renewable energy development, and military training activities; invasive grasses; the potential for an increased risk of wildfire; drought-exacerbated predation; and increasing temperatures and prolonged drought associated with climate change. Our analysis is summarized below. During our review we found no evidence to support that disease, over utilization, or the effects of small population size are affecting the viability of *Y. brevifolia* populations.

We currently have no information to support substantial habitat loss due to development, military training, and renewable energy development now or in the future, beyond the loss of habitat projected under future climate change. Also, we lack sufficient information to project renewable energy development outside of California. We anticipate that avoidance and minimization measures in place on property owned by the State of California and local jurisdictions will mitigate potential losses in that region. We also project habitat loss and disturbance to be minimized on federally managed lands, which currently account for 74 percent of the species distribution.

Our literature review indicates there is a strong probability of habitat loss and degradation through the invasive grass-wildfire cycle that is documented to be an imminent, high magnitude threat in the Mojave Desert (DeFalco *et al*. 2010, entire; Comer *et al*. 2013b, p. 11; Klinger *et al*. 2021, entire). Invasive grasses occur throughout the range of *Yucca brevifolia*, but areas of high invasive cover are limited, and the highest proportion of high invasive grass cover occurred in YUBR North (16 percent). Invasive species, including invasive grasses, are managed to varying degrees on Federal and State lands, though the invasive nature of these species preclude control and eradication. An increased risk of wildfire is estimated in high and middle elevation vegetation communities projected to have high burn severity and low fire frequency in areas that often have not burned for greater than 50 years (Klinger *et al*. 2021, p. 16). The greatest risk and proportion of modeled high burn severity areas occurs throughout YUBR North and in the mountain ranges of southern YUBR South; however, the probability of natural ignition is low, though we project higher human caused ignitions near development centers and recreation areas with high visitation. Overall, future wildfire risk is forecasted to include infrequent, large, moderate to high severity fires including up to 12 and 18 percent of the remaining climate refugia depending on the scenario, but there is uncertainty in where wildfires will occur. We project tree mortality, reduced tree densities, and that recruitment may be limited while the habitat recovers. Due to the infrequent nature of forecasted wildfires in the range of *Y. brevifolia*, the habitat may recover to pre-fire conditions in climate refugia, but the time required for recovery may be extended beyond 100 years due to drought conditions.

The highest magnitude threat is the potential for increased temperatures and drought associated with projected climate change. The bioclimatic models project large areas of the species' range will be climatically unfavorable, and we forecast the potential reduced habitat quality, loss of occupied habitat, and range contractions to occur at lower elevations, depending on the scenario, and the potential for habitat degradation and reduced recruitment at middle elevations. At higher elevations and latitudes, we anticipate climate refugia to persist where all the species needs will continue to be met. Climate refugia may be limited to 1 to 20 percent of the occupied habitat and likely corresponds with areas projected to have infrequent, large, high severity wildfires, though we expect that the proportion of refugia that will burn by the end of the century to be limited to 12 to 18 percent. There is a degree of uncertainty regarding climate projections and in particular precipitation projections. In drought years, we project the potential for reduced recruitment and the potential for severe predation events that may contribute to higher tree mortality and impact tree survival and habitat recovery after wildfire. We also presume that in years of average or high rainfall those threats may be temporarily alleviated. Depending on the duration of the prolonged droughts and the magnitude of rain events it is possible that trees may persist, and periodic recruitment may occur in areas otherwise considered climatically unfavorable. It is not clear if these periods of respite will be sufficient to maintain the species at lower elevations. Therefore, our analysis considers the potential loss of occupied habitat and potential range contractions may occur at lower latitudes and elevations; and marginal habitat areas projected to occur at higher elevations may remain occupied, though tree densities are anticipated to be reduced. Because *Yucca brevifolia* is a long-lived species, there is some uncertainty as to the timing of the potential effects of climate change. We project that *Y. brevifolia* will continue to occupy a relatively large and ecological diverse area under Scenario I [2.2-million ac (880,000 ha)] and a smaller, less ecologically diverse area under Scenario II [1.7-million ac (708,000 ha)] at the end of the century, and the condition of the habitat and demographics will be reduced in the analysis unit at lower latitude and elevation (YUBR South; Table 9-1).

Table 9-1. Summary of Joshua tree population resiliency for each scenario and analysis unit.

Condition	Current	Scenario I	Scenario II
YUBR North	High (4.3)	Moderate To High (3.8)	Moderate (3.0)
YUBR South	High (4.3)	Moderate To High (3.5)	Low To Moderate (2.5)
YUJA North	Moderate (2.3)	Low To Moderate (1.8)	Low (1.5)
YUJA Central	High (4.3)	Moderate (2.5)	Low To Moderate (2.0)
YUJA East	Moderate (2.5)	Low (1.5)	Low (1.3)
Hybrid Zone	Low To Moderate (2.0)	Low To Moderate (2.0)	Low (1.8)

Under the range of threats forecasted in Scenarios I and II, we projected that *Yucca brevifolia* will maintain moderate population resiliency overall with decreased capacity to withstand stochastic variation, including environmental and demographic variability, particularly under Scenario II. Resiliency may be reduced at the end of the century relative to current conditions, particularly at lower elevations (Table 9-2). Our analysis indicates that at least 50 percent [2.2 million ac (880,000 ha)] of the current distribution will be occupied at the end of the century under Scenario I and 40 percent [1.7 million ac (708,000 ha)] will be occupied under Scenario II, though densities may be lower and recruitment more limited, particularly as we project further out into the future. We consider this acreage and the species' broad distribution to confer redundancy. But redundancy will be reduced and potentially limit the ability of the species to withstand potential large-scale wildfires, prolonged drought, and episodes of severe predation, particularly under Scenario II, though no analysis unit are expected to be extirpated under a catastrophic event. Similarly, representation is projected to be reduced compared to current conditions, particularly under Scenario II. Through this analysis we acknowledge the potential loss of occupied habitat at lower elevations and latitudes and the corresponding loss of important genotypes in the more arid portions of the species distribution and that the remaining genetic variability may be more limited and not as well adapted to the warmer temperatures forecasted for higher latitudes and elevations. However, we forecast that *Y. brevifolia* will persist in climatic refugia in topographically diverse terrain dispersed across the remaining occupied areas of the species' distribution, despite recent wildfires and the potential for infrequent, large, high severity wildfires. Species needs (e.g., sufficient pollinators, survival, and appropriate recruitment conditions to maintain population abundance) are likely to continue to be met in climate refugia including as much as 1-million acres (400,000 ha) under Scenario I but the total area of climate refugia may be limited to 320,000 ac (128,000 ha) under Scenario II. We considered the possibility of potential habitat expansion in the future; but project that it will be limited by dispersal distance and the general lack of continuity between occupied habitat and habitat forecasted to be climatically favorable in the future. Therefore, we did not include potential habitat expansion in our projections for resiliency, redundancy, or representation. We project that forecasted potential losses in occupied habitat at the end of the century may reduce resiliency, redundancy, and representation and lead to reduced *Y. brevifolia* viability into the future, particularly under Scenario II.

Table 9-2. Summary of Yucca brevifolia viability analysis.

Condition	Current	Scenario I	Scenario II
Resiliency	HIGH (4.3)	MODERATE TO HIGH (3.6)	MODERATE (2.7)
Redundancy	High. Analysis units spread across a very large area of mostly intact habitat that supports resource needs.	Decrease in the ability to withstand catastrophic events due to decreases in distribution and populations size due to the potential loss of occupied habitat at lower elevations and latitudes.	Greater reduction in the ability to withstand catastrophic events due to loss of occupied habitat at lower elevations and latitudes and reduced abundance and recruitment at middle elevations, compared to Scenario I. A catastrophic event is unlikely to extirpate either analysis unit; but YUBR South is more vulnerable.
Representation	High. Analysis units spread across a very large area of diverse ecological habitat and a broad latitudinal gradient.	Decrease in the ability to adapt to change environmental conditions due to the potential loss of occupied habitat at lower elevations and latitudes and associated decrease in ecological diversity.	Greater reduction in adaptive capacity due to the likely loss of arid adapted genotypes at lower latitudes and higher latitude genotypes may be poorly adapted to warming conditions, compared to Scenario I. Species life history characteristics limit dispersal and ability to adapt to rapid changes in climate conditions.
Species Viability	Viable	Decreased	Decreased

9.2 *Yucca jaegeriana*

Yucca jaegeriana is currently considered viable and viability is forecasted to decrease in the future. The species' distribution is currently large, approximately 4.9-million ac (1.9-million ha), and it occupies a diverse region of topographic and ecological diversity that spans a large latitudinal gradient of approximately 300 mi (483 km), including potentially millions of individual trees and clones that confer both redundancy and representation. The distribution of *Y. jaegeriana* is reduced in terms of ecological diversity compared to *Y. brevifolia*, largely because YUJA Central and YUJA East occur in areas of reduced topographic heterogeneity and a corresponding low number of ecoregions. Abundance is currently, and likely historically, low to moderate condition and occupancy is presumed throughout the distribution, though tree densities vary and are projected to be lower in warm environments. Population resiliency is currently moderate to high across the three analysis units based on the current low to moderate levels of threat. Resiliency is reduced relative to *Y. brevifolia*, due to lower condition for demographic parameters (tree density and recruitment) and habitat quality (Table 9-3). There is currently evidence of drought stress at lower latitudes and elevations due to rising temperatures and drought conditions with the potential for tree mortality and reduced recruitment, including drought-exacerbated predation, though these potential effects are not as well substantiated as they are for *Y. brevifolia*.

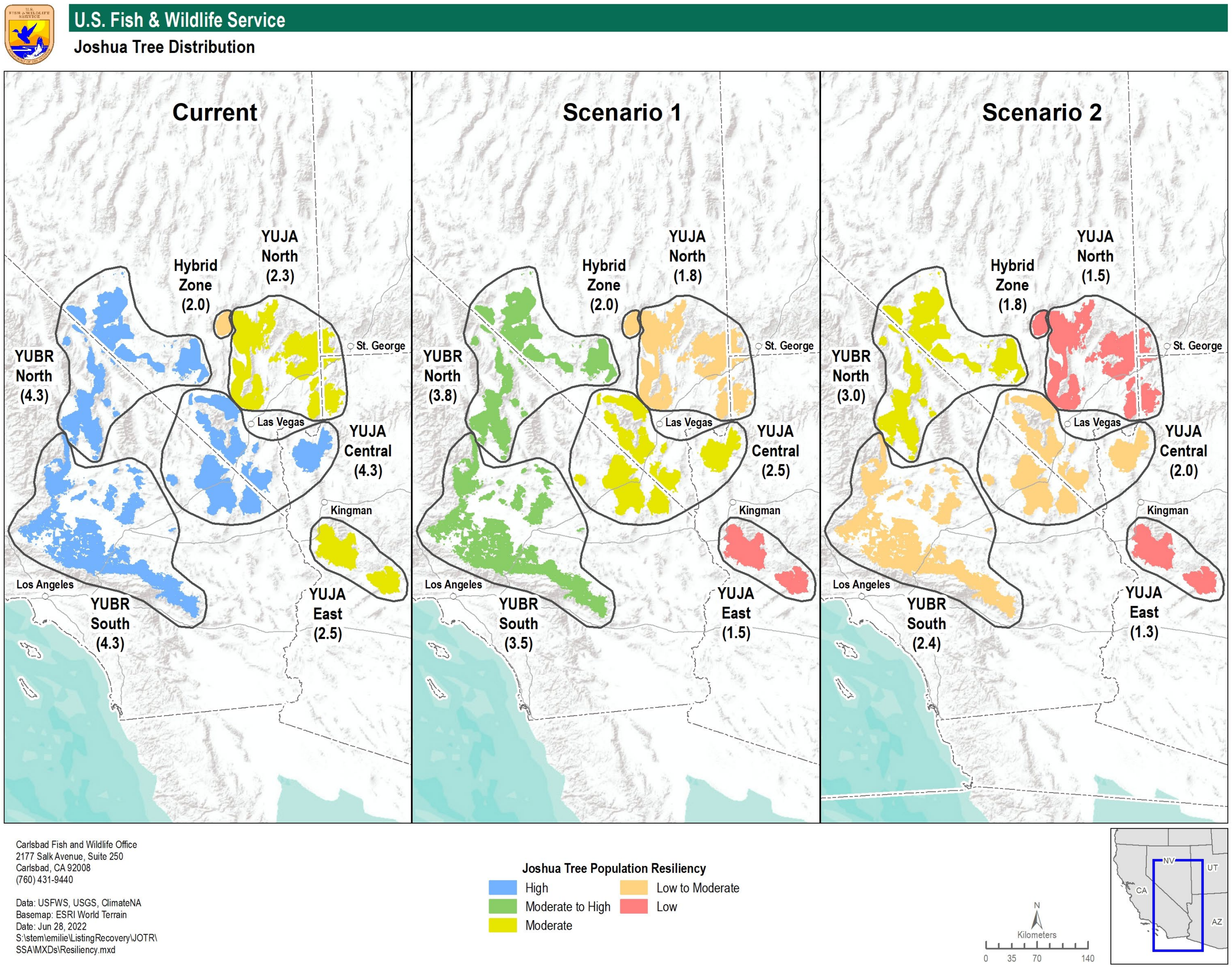

Figure 9-1. Summary of Joshua tree population resiliency for each scenario and analysis unit.

We evaluated potential threats to *Yucca jaegeriana* now and in the future including habitat loss due to urbanization, renewable energy development, and military training activities; invasive grasses; increased risk of wildfire; predation; and increasing temperatures and prolonged drought associated with climate change. Our analysis is summarized below. During our review we found no evidence to support that disease, over utilization, or the effects of small population size are having an impact on *Y. jaegeriana* individuals or populations.

We currently have no information to support substantial habitat loss due to development, military training, and renewable energy development now or in the future, beyond that forecasted for climate change and described below. Also, we lack sufficient information to project renewal energy development outside of California. We forecast habitat loss and disturbance to be minimized on military lands and lands owned by the Federal government, which currently account for 89 percent of the species current distribution. In Arizona, Nevada, and Utah there are less regulatory protections in place on private land, and privately owned land accounts for only 7 percent of the distribution.

The range of *Yucca jaegeriana* is at increased risk of wildfire currently and in the future. There is evidence of the establishment of the invasive grass-wildfire cycle in YUJA North that has high invasive grass cover currently (30 percent) and in the future (32 percent). Invasive species, including invasive grasses, are managed to varying degrees on Federal and State property, though the invasive nature of these species precludes control and eradication. High invasive grass cover in some areas is the result of multiple wildfires in the recent past. Approximately half of YUJA North and YUJA Central are characterized by a high probability of natural ignitions due to lightning associated with monsoonal storm events and increased fire frequency; and a third is characterized by high burn severity. Although the area of projected high burn severity is smaller than YUBR North, they occur in the vicinity of areas projected to have high frequency fires, increasing the probability of large wildfire events. Overall, future wildfire risk is forecasted to include high frequency, low severity fires at low and middle elevation plant communities and infrequent, large, moderate to high severity fires at higher elevations. We forecast tree mortality and reduced tree densities, and that recruitment may be substantially limited in areas of frequent fires. Habitat recovery may take 80 to 100 years or more, and recovery may be extended due to drought conditions.

The highest magnitude threat for *Yucca jaegeriana* is also the potential for increased temperatures and drought associated with projected climate change. The bioclimatic models project large areas of the species' range will be climatically unfavorable, and we forecast the potential loss of occupied habitat and range contractions to occur at lower elevations, particularly at the southeastern portion of the range that is currently experiencing greater drought stress than recorded historically. We also forecasted the potential for habitat degradation and reduced recruitment at middle elevations, though we project that most of these areas will remain occupied. Climate refugia is anticipated at higher elevations and latitudes which may be limited to 1 to 20 percent of the current distribution, depending on the scenario and analysis unit, where all species needs will continue to be met. There is a higher risk of wildfire in *Y. jaegeriana* climate refugia due to the increased probability of natural ignitions and fire frequency compared to *Y. brevifolia*. There is uncertainty regarding climate projections and in particular precipitation. In drought years, we project the potential for reduced recruitment and the potential for severe predation events that may contribute to higher tree mortality at lower elevations. We also presume that in years of average or high rainfall those threats may be temporarily alleviated. Depending on the duration of the prolonged droughts and the magnitude of rain events it is possible that trees may persist, and periodic recruitment may occur in areas otherwise considered climatically unfavorable. It is not clear if these periods of respite will be sufficient to maintain the species at lower elevations, so our analysis assumes the potential loss of occupied habitat and range contractions may occur at lower latitudes and elevations. Marginal habitat areas at higher elevations and latitudes will remain occupied, though tree densities are forecasted to be reduced. Because *Y. jaegeriana* is a long-lived species, there is some uncertainty as to the timing of the potential effects of climate change. We project that *Y. jaegeriana* will continue to occupy a relatively large and ecological diverse area under Scenario I [2.9-million ac (1.2-million ha)] at the end of the century and a smaller, less ecologically diverse area under Scenario II [2.3-million ac (913,200 ha)]. The condition of the habitat and demographics will be reduced at the end of the century, particularly under Scenario II, due to both projected climate change impacts and the increased risk of wildfire.

Under the range of threats forecasted in Scenarios I and II, we projected that *Yucca jaegeriana* will maintain low to moderate population resiliency overall with a decreased capacity to withstand stochastic variation, including environmental and demographic variability, particularly under Scenario II. Resiliency may be reduced at the end of century relative to current conditions depending on the scenario, particularly in YUJA East and in lower elevation areas (Table 9-3). Redundancy is projected to be reduced due to decreases in distribution and population size as a result of potential loss of occupied habitat at lower elevations and latitudes. Our analysis indicates that at least 60 percent [2.9-million ac (1.2-million ha)] of the current distribution will be occupied under Scenario I and 47 percent [2.3-million ac (913,200 ha)] will be occupied under Scenario II, in a smaller and less ecologically diverse area, at the end of the century. We consider this acreage and the species' broad distribution to confer reduced redundancy for the species to withstand the increased risk of wildfires, prolonged drought, and episodes of severe predation; and no analysis unit is expected to be extirpated under a catastrophic event. Similarly, representation is projected to be reduced compared to current conditions, particularly under Scenario II. Through this analysis, we acknowledge the potential for the loss of occupied habitat at lower elevations and latitudes and the corresponding loss of potentially important genotypes in the more arid portions of the species' distribution and that the remaining genetic variability may be more limited and not as well adapted to the warmer temperatures forecasted for higher latitudes and elevations. However, we forecast that *Y. jaegeriana* will persist in climatic refugia in topographically diverse terrain dispersed across the remaining occupied areas of the species' distribution, despite recent wildfires and the potential for infrequent, large, high severity wildfires. Species needs (e.g., sufficient pollinators, survival, and appropriate recruitment conditions to maintain population abundance) are likely to continue to be met in climate refugia totaling approximately 1.5-million acres (400,000 ha) under Scenario I. However, the total area of climate refugia may be limited to 608,000 ac (243,200 ha) under Scenario II. We project that as much as 12 to 18 percent of modeled climate refugia will be impacted by wildfire. We considered the possibility of potential habitat expansion in the future, but project that it will be limited by dispersal distance and the general lack of continuity between currently occupied habitat and habitat forecasted to be climatically favorable in the future. Therefore, we did not include potential habitat expansion in our projections for resiliency, redundancy, or representation. We project that forecasted potential losses in occupied habitat at the end of the century may reduce resiliency, redundancy, and representation and lead to reduced *Y. jaegeriana* viability into the future, particularly under Scenario II.

Table 9-3. Summary of *Yucca jaegeriana* viability analysis.

Condition	Current	Scenario I	Scenario II
Resiliency	Moderate (2.9)	Low To Moderate (1.9)	Low (1.6)
Redundancy	High. Analysis units spread across a very large area of mostly intact habitat that supports resource needs.	Decrease in the ability to withstand catastrophic events due to decreases in distribution and population size due to the potential loss of occupied habitat at lower elevations and latitudes.	Greater reduction in the ability to withstand catastrophic events due to substantial loss of occupied habitat at lower latitudes and elevations, and reduced abundance and recruitment at middle elevations, compared to Scenario I. A catastrophic event is unlikely to extirpate any analysis unit; but YUJA East is more vulnerable.
Representation	High. Analysis units spread across a very large area of diverse ecological habitat and a broad latitudinal gradient.	Decreased due to the potential loss of occupied habitat at lower elevations and latitudes and associated decrease in ecological diversity, which is already lower.	Greater reduction in adaptive capacity due to the likely loss of arid adapted genotypes at lower latitudes and higher latitude genotypes may be poorly adapted to warming conditions, compared to Scenario I. A larger proportion of the species distribution occurs at lower elevations and there is the potential for a greater loss in representation due to the effects of climate change. Species life history characteristics limit dispersal and ability to adapt to rapid changes in climate conditions.
Species Viability	Viable	Decreased	Decreased

CHAPTER 10. REFERENCES

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APPENDIX A

Adaptive Capacity Assessment

Analysis based on Thurman *et al*. 2020

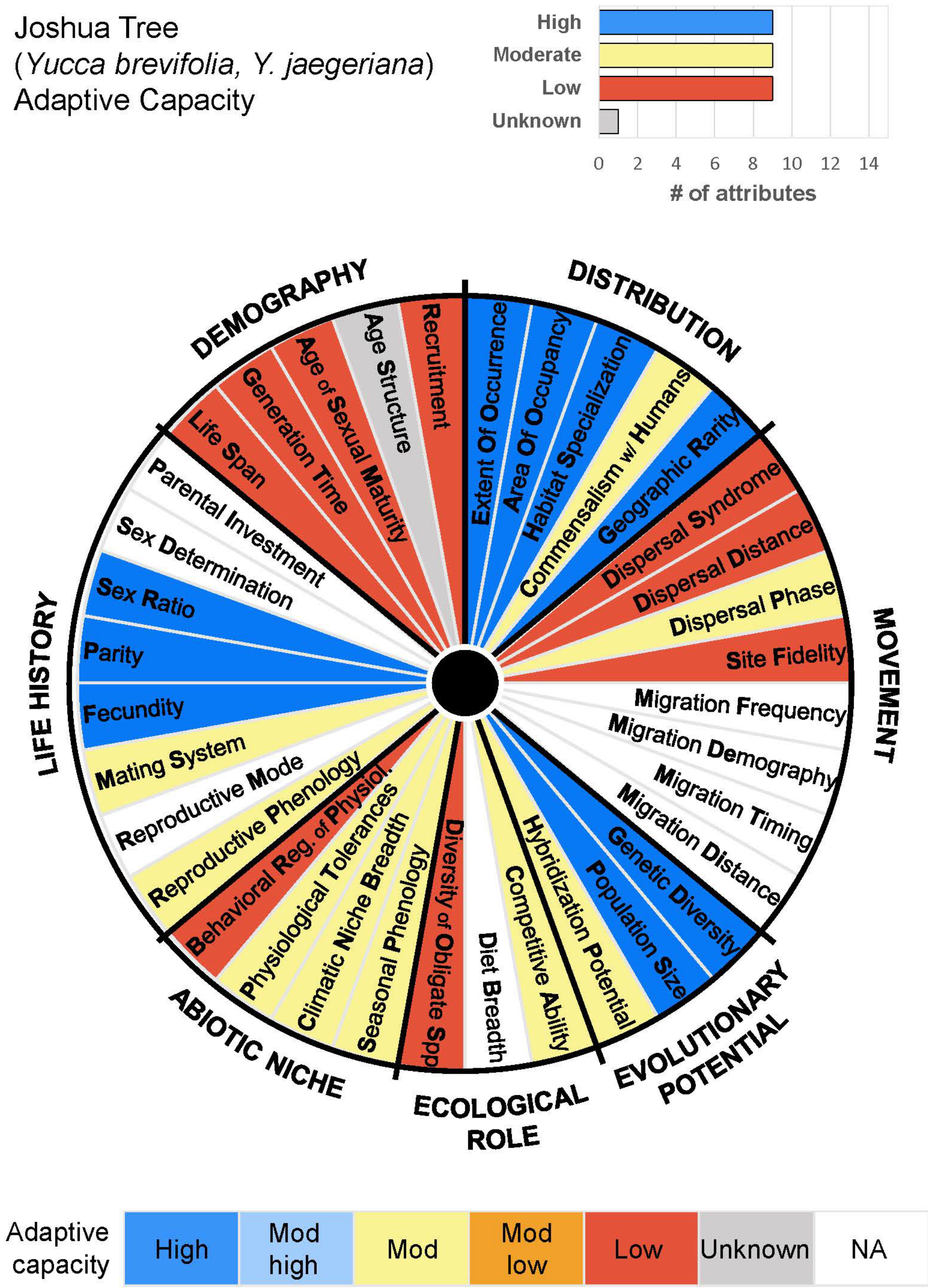

Figure A-1. Graphical representation of the different life history, demographic, distribution, movement, evolutionary potential, ecological role and abiotic nice factors evaluated to assess adaptive capacity and the corresponding level of adaptive capacity afforded by the trait.

APPENDIX B

Regulatory Mechanisms

B.1 Federal

Approximately 82 percent of the land within the distribution of Joshua trees is federally owned (Table 4-1). Agencies with a substantial presence in the region include BLM, NPS, Service, USFS, and DoD. Management of these areas depends on the agency, based on each agency's respective regulatory framework, though some existing regulatory mechanisms are not agency-specific.

B.1.1 National Environmental Policy Act

All Federal agencies are required to comply with the National Environmental Policy Act (NEPA) of 1970 (as amended; 42 USC §§ 4321 *et seq*.), which is a procedural statute. Prior to implementation of projects with a Federal nexus, NEPA requires the agency to analyze the project for potential impacts to the human environment, including natural resources. If an Environmental Impact Statement is prepared for an agency action, the agency must provide a full and fair discussion of significant environmental impacts and inform decision makers and the public of reasonable alternatives that would avoid or minimize adverse impacts or enhance the quality of the human environment (40 CFR § 1502.1). The public notice provisions of NEPA provide an opportunity for interested parties to review proposed actions and provide recommendations to the implementing agency. The NEPA process provides the opportunity for lead agencies and the public to recommend avoidance and minimization for impacts to Joshua trees.

B.1.2 Federal Land Policy and Management Act of 1976

The Federal Land Policy and Management Act (FLPMA) (as amended; 43 USC §§ 1701-1785) authorizes the BLM to manage public lands under the principles of multiple use and sustained yield. Section 202 of FLMPA directs the BLM to prepare resource management plans (RMPs) that establish the basis for actions and approved uses on public lands for specific planning areas (BLM 2005, pp. 1, 14). Through these plans, habitat for all federally listed or State listed species will be managed to maintain or increase current species populations. BLM has also issued policy guidance to implement its obligations under FLPMA. These include BLM's Integrated Vegetation Management Handbook H-1740-2, which guides BLM's various programs to use an interdisciplinary and collaborative process to plan and implement a set of actions that improve biological diversity and ecosystem function that promote and maintain native plant communities that are resilient to disturbance and invasive species (BLM 2008, p. 2), and BLM's Travel and Transportation Handbook H-8342, which clarifies policies and establishes procedures for implementing travel and transportation planning and management in land use and implementation plans (BLM 2012b, pp. 1–4). Additionally, BLM Manual Section MS-6840, Release 6-125 (BLM 2008, pp. 1–48) provides guidance with respect to sensitive species managed as a BLM sensitive species which are defined as "species that require special management or considerations to avoid potential future listing" (BLM 2008, Glossary, p. 5). Under this policy, BLM initiates proactive conservation measures including programs, plans, and management practices to reduce or eliminate threats affecting the status of the species, or improve the condition of the species' habitat on BLM-administered lands (BLM 2008, Glossary, p. 2). Joshua trees (*Yucca brevifolia*, *Y. jaegeriana*) are not sensitive species within any of the states where they occur. Therefore, Joshua trees are not conserved or protected as a sensitive species and do not have status on BLM lands.

B.1.3 Clean Air Act

The Clean Air Act (CAA) amended in 1990 regulates air emissions from both stationary (e.g., factories and chemical plants) and mobile sources (e.g., cars, trucks, and off-road vehicles) to protect public health and regulate hazardous air pollutants. The CAA sets standards for greenhouse gas emissions associated with global warming, and fuel economy standards to reduce the use of fossil fuels. Although these regulations may contribute toward reduced greenhouse gas emissions in the United States, they are unlikely to alter the trajectory of projected climate change and potential climate change impacts on Joshua trees that are ultimately tied to global emission rates.

B.1.4 National Forest Management Act

The National Forest Management Act (NFMA) (16 U.S.C. § 1600 *et seq.*) requires the USFS to develop a planning rule under the principles of the MUSY of 1960 (16 U.S.C. 528–531). The NFMA outlines the process for the development and revision of the land management plans and their guidelines and standards [16 U.S.C. 1604(g)].

A new National Forest System (NFS) land management planning rule (Planning Rule) was adopted by the USFS in 2012 (77 FR 21162; April 9, 2012). The new Planning Rule guides the development, amendment, and revision of land management plans for all units of the NFS to maintain and restore NFS land and water ecosystems while providing for ecosystem services and multiple uses. Land management plans (also called Forest Plans) are designed to: (1) Provide for the sustainability of ecosystems and resources; (2) meet the need for forest restoration and conservation, watershed protection, and species diversity and conservation; and (3) assist the USFS in providing a sustainable flow of benefits, services, and uses of NFS lands that provide jobs and contribute to the economic and social sustainability of communities (77 FR 21261; April 9, 2012). A land management plan does not authorize projects or activities, but projects and activities must be consistent with the plan (77 FR 21261; April 9, 2012). The plan must provide for the diversity of plant and animal communities, including species-specific plan components in which a determination is made as to whether the plan provides the "ecological conditions necessary to . . . contribute to the recovery of federally listed threatened and endangered species . . ." (77 FR 21265; April 9, 2012).

The Record of Decision for the final Planning Rule was based on the analyses presented in the Final Programmatic Environmental Impact Statement, National Forest System Land Management Planning (77 FR 21162–21276; April 9, 2012), which was prepared in accordance with the requirements of the NEPA. In addition, the NFMA requires land management plans to be developed in accordance with the procedural requirements of the NEPA, with a similar effect as zoning requirements or regulations as these plans control activities on the national forests and are judicially enforceable until properly revised (Wilkinson and Anderson 2002, entire).

A Species of Special Concern (SSC) is defined in the 2012 Planning Rule and in regulation [36 CFR 219.9(c)], as "a species, other than federally recognized threatened, endangered, proposed, or candidate species, that is known to occur in the plan area and for which the regional forester has determined that the best available scientific information indicates substantial concern about the species' capability to persist over the long-term in the plan area." The 2012 Planning Rule requires Regional Foresters to identify SCC for plan revision, and, when identified for a National Forest, monitoring plans are changed as needed (77 FR 21250, 21267; April 9, 2012).

Joshua trees' distribution includes 131,346 ac (53,154 ha) in lands designated as National Forest and are managed under a Land and Resource Management Plan for each Ranger District.

B.1.5 Sikes Act and Sikes Act Improvement Act of 1997

The Sikes Act (16 U.S.C. 670) authorizes the Secretary of Defense to develop cooperative plans with the Secretaries of Agriculture and the Interior for natural resources on public lands. The Sikes Act Improvement Act of 1997 requires DoD installations to prepare INRMPs that provide for the conservation and rehabilitation of natural resources on military lands consistent with the use of military installations to ensure the readiness of the Armed Forces. These INRMPs incorporate, to the maximum extent practicable, ecosystem management principles and provide the landscape necessary to sustain military land uses. While INRMPs are not technically regulatory mechanisms because their implementation is subject to funding availability, they can be an added conservation tool in promoting the recovery of endangered and threatened species on military lands. Among others, each INRMP must, to the extent appropriate and applicable, provide for fish and wildlife management; fish and wildlife habitat enhancement or modification; wetland protection, enhancement, and restoration where necessary to support fish and wildlife; and enforcement of applicable natural resource laws. Approximately 10 percent [830,828 ac (336,368 ha)] of Joshua trees distribution is on DoD land including the following installations: Edwards Air Force Base, MCAGCC, NAWS China Lake, Fort Irwin, and Nellis Air Force. Each installation has an INRMP which includes measures that address Joshua trees and their habitat.

B.1.6 National Park Service Organic Act of 1916

The National Park Service Organic Act of 1916 (16 U.S.C. 1) established the NPS as an agency under the direction of the Secretary of the Interior with the stated purpose of promoting use of national park lands while protecting them from impairment. Specifically, the Act declares that the National Park Service has a dual mission, both to conserve park resources and provide for their use and enjoyment "in such a manner and by such means as will leave them unimpaired" for future generations (16 U.S.C. 1). While the Organic Act unified park management into a national system, national parks also have individual legislation and management systems. Each park is created by an individual legislative act of Congress. Joshua trees occur on approximately 1-million ac (411,045 ha) within JTNP, Death Valley National Park, and the Mojave National Preserve. Destroying, injuring or removing Joshua trees is prohibited in national parks. In addition, JTNP actively monitors the population (Graver 2022, entire), conducts habitat restoration, and is actively managing potential climate change refugia.

B.1.7 Organic Administration Act of 1897 and the Multiple-Use, Sustained-Yield Act of 1960

The USFS Organic Act of 1897 (16 U.S.C. 475–482) established general guidelines for administration of timber on USFS lands, which was followed by the Multiple-Use, Sustained-Yield Act (MUSY) of 1960 (16 U.S.C. 528–531), which broadened the management of USFS lands to include outdoor recreation, range, watershed, and wildlife and fish purposes.

B.1.8 Wilderness Act

The Wilderness Act of 1964 (16 U.S.C. 1131–1136) provides protection of habitat from most forms of development, though no single agency is responsible for administration of lands provided this designation, which are designated (or modified) by Congress. The Wilderness Act prohibits commercial enterprises and permanent roads within Wilderness areas and restricts temporary roads, motorized and mechanical transport, and structures, but does not prohibit all commercial uses (such as, grazing). Some areas within the region have been designated as Wilderness through the California Desert Protection Act of 1994 (Public Law 103-433) and the Omnibus Public Land Management Act of 2009 (Public Law 111-11).

B.1.9 Endangered Species Act

Joshua trees benefit from critical habitat designated for federally listed species that co-occur within the distribution of Joshua trees. Critical habitat has been designated for 20 species but 98 percent of the acreage is attributable to critical habitat for the federally threatened desert tortoise [Mojave population DPS (*Gopherus agassizii*); desert tortoise] (Table B1; Figure B1). The physical and biological features of desert tortoise critical habitat may also benefit Joshua trees including sufficient vegetation for shelter and habitat protection from disturbance and human-caused mortality.

B.1.10 California Desert Protection Act

The California Desert Protection Act established Death Valley and Joshua Tree National Parks and the Mojave National Preserve. In addition, it 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.

B.1.11 Desert Renewable Energy Conservation Plan

The Desert Renewable Energy Conservation Plan (DRECP) designated development focus areas in California that would apply a streamlined review process to applications for projects that generate renewable energy on BLM lands. The DRECP contains measures to avoid removing individual plants by avoiding areas classified as Joshua tree Woodland (BLM 2016a, II, P. 3-55). These measures would reduce the number of individual trees and habitat potentially lost to renewable energy development on designated lands.

B.2 State

The following State regulations minimize impacts to Joshua tree associated with the collection of trees.

B.2.1 Arizona Native Plant Law

Yucca jaegeriana are salvage protected restricted native plants and can only be collected with a permit from the Arizona Department of Agriculture

B.2.2 California Desert Native Plants Act

California law prohibits unlawful harvesting of desert plants on both public and privately owned lands, without a permit. This regulation applies to all desert habitats in California.

B.2.3 California Species of Special Concern and California Environmental Quality Act

As described by (Comrack *et al*. 2008, entire), a California SSC is an administrative designation and carries no formal legal status. California SCCs should be considered during the environmental review process under the California Environmental Quality Act (CEQA; California Public Resources Code §§ 21000-21177). Similar to the Federal NEPA, the CEQA requires State agencies, local governments, and special districts to evaluate and disclose impacts from "projects" in the State. Section 15380 of the CEQA Guidelines indicates that California SCCs should be included in an analysis of project impacts if they can be shown to meet the criteria of sensitivity outlined therein. Joshua trees are not a California SCC.

B.2.4 California Climate Policies

The State of California has a number of policies and regulations to help reduce greenhouse gas emissions through the State's climate adaptation and resiliency plan, reduced emissions, promotion of electrical vehicles, and penalties for polluters (Berkeley Law 2022). Senate Bill (SB) 32 and Assembly Bill (AB) 32 require California to reduce emission and develop policies to meet stated goals and California's climate registry catalogs and verifies greenhouse gas emission reductions (SB 1771). Legislation has been adopted to require energy procurement from renewable resources, improve energy efficiency of existing buildings, and promote investment in electric vehicle charging infrastructure (SB 100; SB 350; AB 1236). Transportation legislation includes improvements in efficiency, emission reduction (SB 1), and to mitigate the vehicle miles traveled associated with new development (SB 375). AB 617 increases air monitoring and penalties for polluters who exceed limitations in vulnerable communities and projects are funded in disadvantaged communities by directing funding from cap-and-trade revenues (SB 535; AB 1550). The State's climate adaptation and resiliency strategy is called for in several bills (AB 1482; SB 246; SB 379; AB 2800; SB 1035; and SB 30) which require state agencies to account for climate change in planning new construction, including oversight and reporting (AB 197). State law set emission standards for passenger vehicles (AB 1493). Legislation requires a strategy for reducing short-lived climate pollutant such as methane (SB 605; SB 1383).

B.2.5 Nevada State Protections

All members of the *Yucca* genus, are protected in the state of Nevada from commercial collection (Nev. Rev. Stat. 527.060). Commercial removal and sale of *Yucca* harvested from state, county, or privately owned land requires a permit from the Nevada State Forester Fire-warden.

We are not aware of other regulations or ordinances in Arizona, Nevada, or Utah that would reduce impacts to Joshua trees.

B.3 Jurisdiction Specific Ordinances

The following ordinances outline measures to avoid and minimize impacts to Joshua trees and only occur within jurisdictions in the State of California. Recently established protections in the San Bernardino County and the cities of Palmdale and Yucca Valley are related to *Yucca brevifolia's* status as a candidate under CEQA; should the California Fish and Game Commission determine that listing is not be warranted, these regulations will no longer be in effect in these jurisdictions.

B.3.1 Inyo County

The planning commission may consider impacts to Joshua trees during the issuance of conditional use and grading permit; however, there are no specific ordinances to avoid or mitigate potential impacts.

B.3.2 City of Bishop, California

Unique natural and vegetative features must be included on development plans reviewed for conditional use permits, including trees greater than 4 inches in diameter; however, there are no specific ordinances to avoid or mitigate potential impacts.

B.3.3 City of Hesperia, California

Joshua trees on single-family residential tract, multiple-family residential, commercial, and industrial developments are identified and avoided, where feasible. If impacts are not avoidable they will be mitigated through transplanting or adoption as specified in the Protected Native Vegetation (PL-16) and Protected Plant Policy (PL-17).

B.3.4 City of Palmdale, California

Joshua tree and Native Desert Preservation ordinance protects and preserves desert vegetation, and in particular *Yucca brevifolia*.

B.3.5 City of Victorville, California

Yucca brevifolia on undeveloped lands are protected by City Ordinance No. 1224. 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.

B.3.6 City of Yucca Valley, California

A permit issued by the Community Development Director is required to remove *Yucca brevifolia*, with the exception of the fruit, under City Ordinance 140-Desert Native Plant Protection. The ordinance applies on all private lands within the town of Yucca Valley and public lands owned by Yucca Valley.

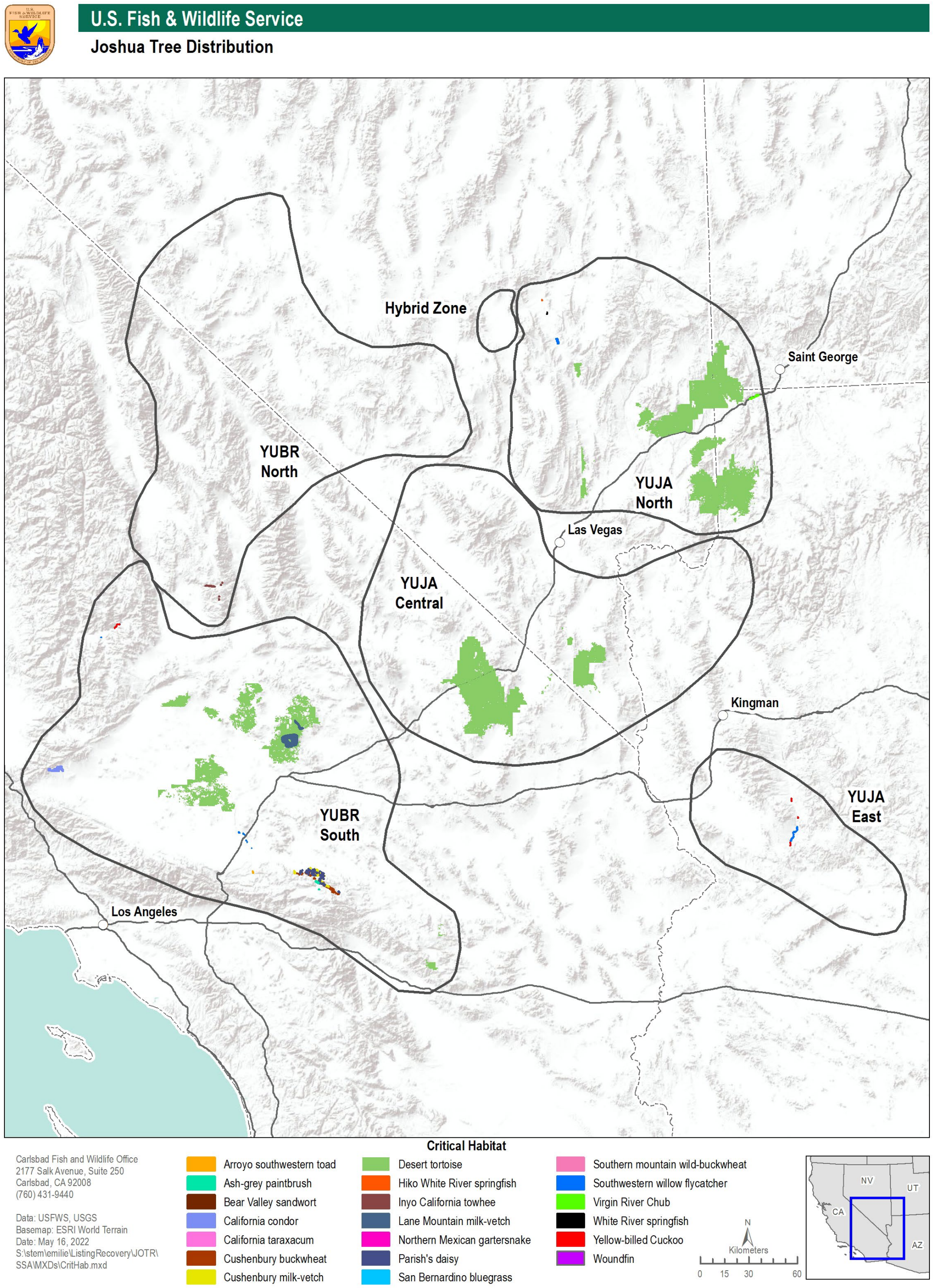

Figure B-1. Areas of critical habitat designated within the distribution of *Yucca brevifolia* and *Y. jaegeriana.*

Table B-1. Acres (hectares) of critical habitat designated within the distribution of *Yucca brevifolia* and *Y. jaegeriana*.

Species	YUBR North[1]	YUBR South[1]	YUJA North[1]	YUJA Central[1]	YUJA East[1]	Hybrid Zone[1]	Grand Total[1]
Arroyo (=arroyo southwestern) toad		87 (35)					87 (35)
Ash-grey paintbrush		252 (102)					252 (102)
Bear Valley sandwort		251 (102)					251 (102)
California condor		3,039 (1,230)					3,039 (1,230)
California taraxacum		0					0
Cushenbury buckwheat		4,419 (1,789)					4,419 (1,789)
Cushenbury milk-vetch		3,872 (1,568)					3,872 (1,568)
Desert tortoise		387,369 (156,830)	593,109 (240,125)	443,385 (179,508)			1,423,864 (576,463)
Hiko White River springfish			6 (3)				6 (3)
Inyo California towhee	732 (296)						732 (296)
Lane Mountain milk-vetch		14,169 (5,736)					14,169 (5,736)
Northern Mexican gartersnake					27 (11)		27 (11)
Parish's daisy		3,762 (1,523)					3,762 (1,523)
San Bernardino bluegrass		0					0
Southern mountain wild-buckwheat		252 (102)					252 (102)
Southwestern willow flycatcher		155 (63)	768 (311)		431 (175)		1,353 (548)
Virgin River Chub			199 (81)				199 (81)
White River springfish			16 (6)				16 (6)

Species	YUBR North[1]	YUBR South[1]	YUJA North[1]	YUJA Central[1]	YUJA East[1]	Hybrid Zone[1]	Grand Total[1]
Woundfin			199 (81)				199 (81)
yellow-billed cuckoo (western DPS)		136 (55)			120 (49)		256 (104)
Total Critical Habitat	**732 (296)**	**417,763 (169,135)**	**594,298 (240,606)**	**443,385 (179,508)**	**578 (234)**	**0**	**1,456,757 (589,780)**
Acreage of Analysis Unit	**2,129,113 (861,989)**	**2,288,162 (926,381)**	**2,065,476 (836,225)**	**2,089,163 (845,225)**	**754,821 (305,595)**	**121,147 (49,047)**	**9,447,883 (3,825,054)**
Percent of Analysis Unit	**0**	**18**	**29**	**21**	**0**	**0**	**15**

[1] Acres (Hectares).

APPENDIX C

Estimated Wildfire Risk

Estimated wildfire risk including the probability of natural ignitions, fire frequency and burn severity (Klinger *et al*. 2021, entire).

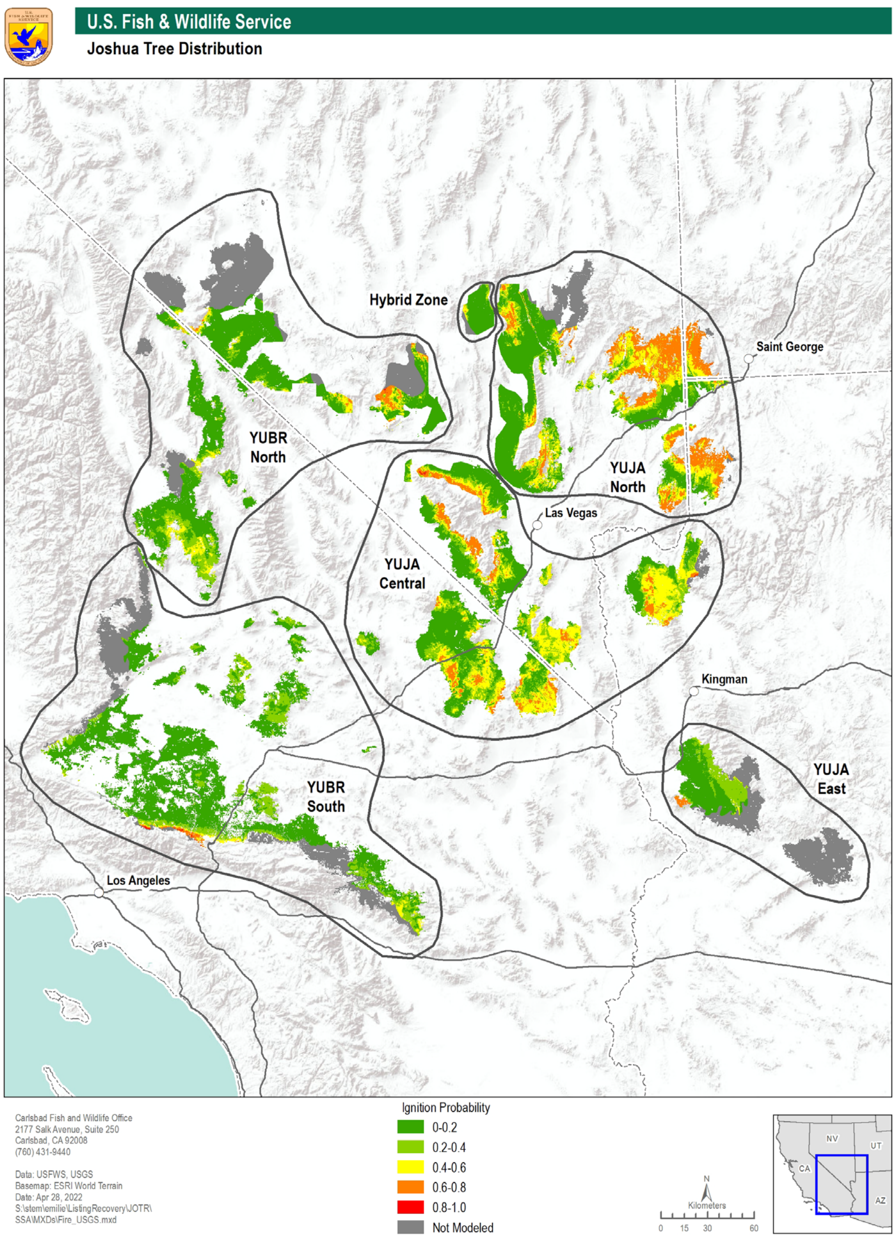

Figure C-1. Estimated ignition probability throughout the distribution of Joshua trees; areas greater than 0.2 indicate increased probability of ignitions.

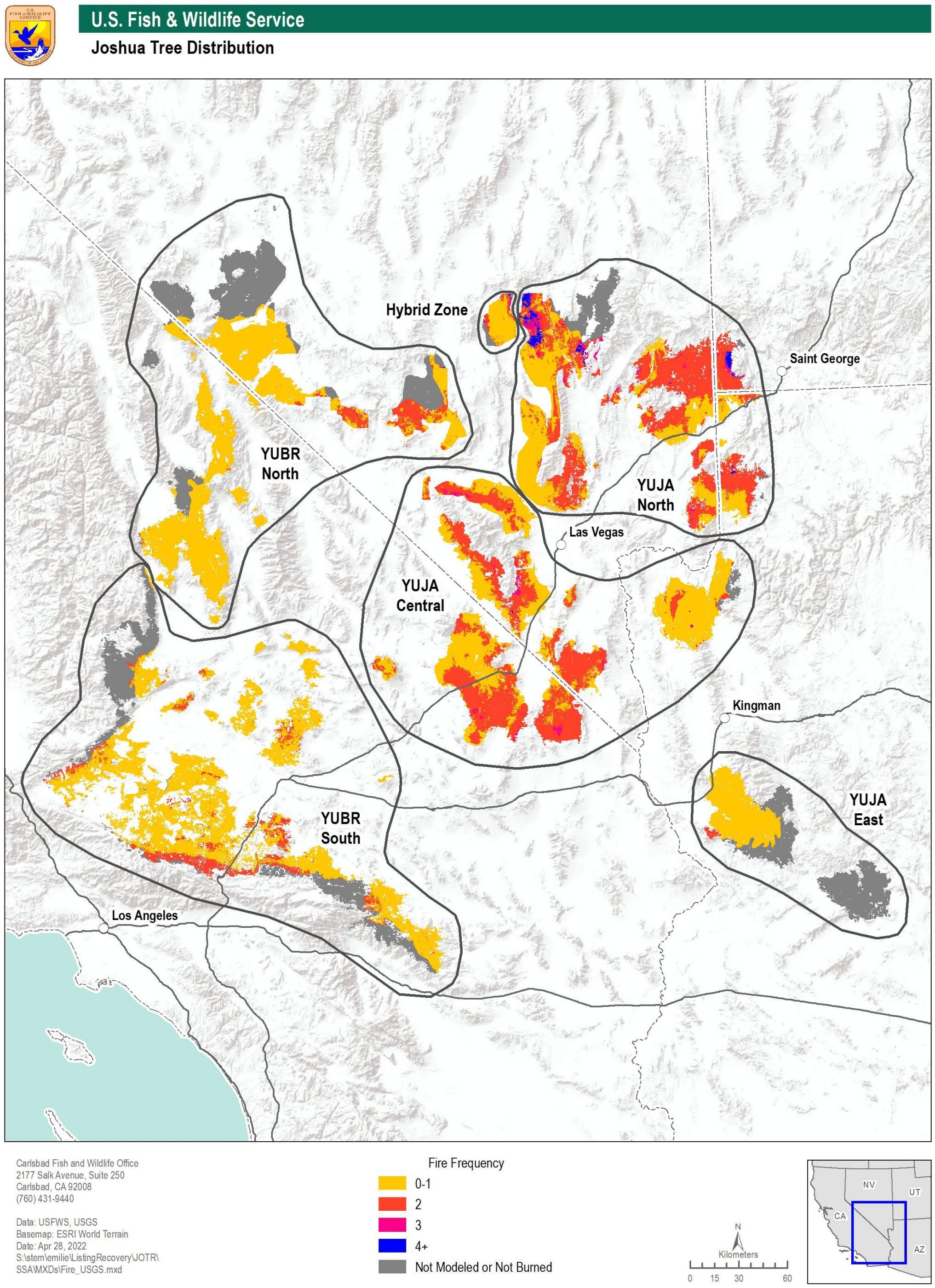

Figure C-2. Estimated fire frequency throughout the distribution of Joshua trees; areas greater than 2 fires indicate increased fire frequency.

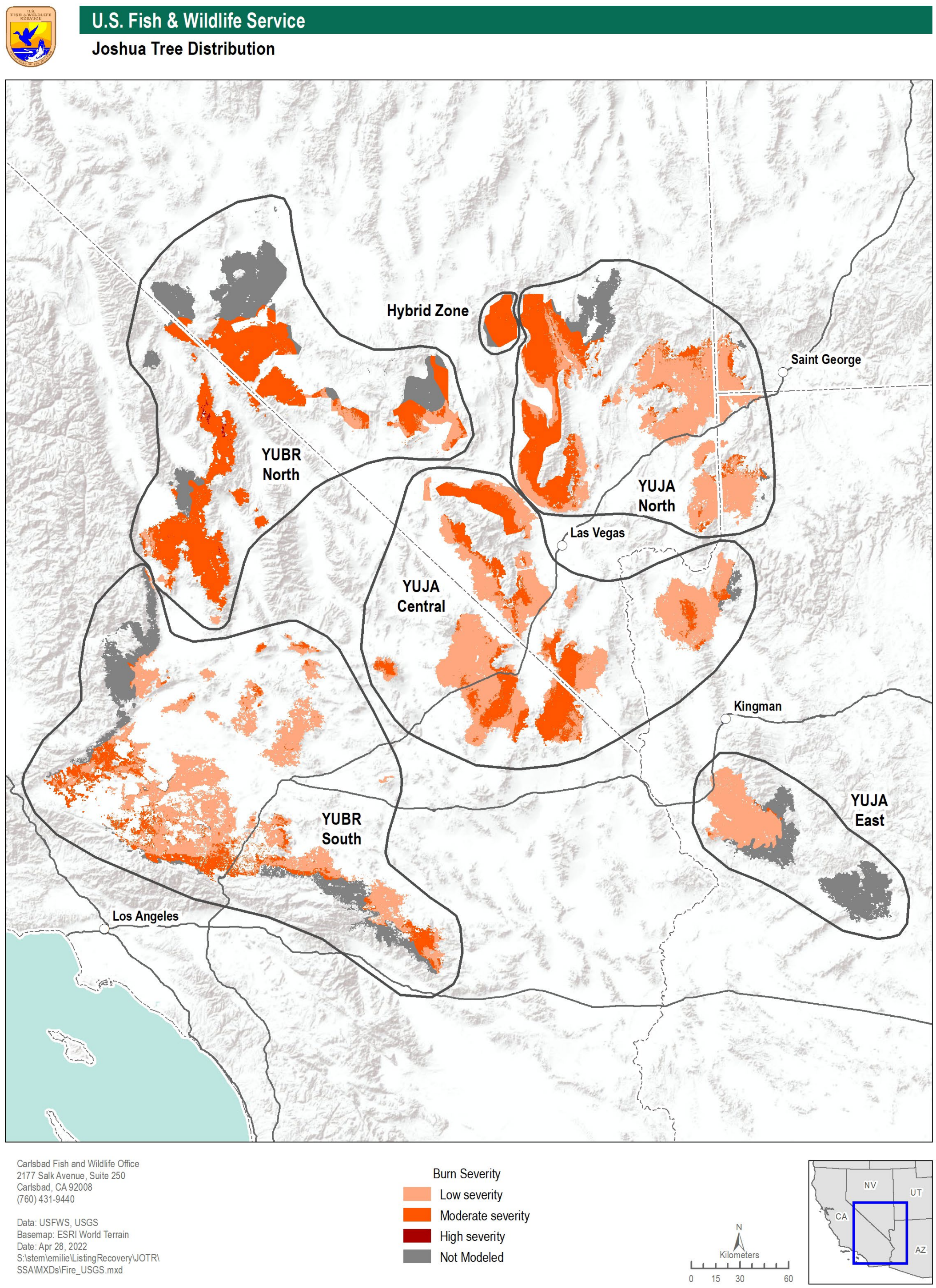

Figure C-3. Estimated burn severity throughout the distribution of Joshua trees.

APPENDIX D

Elevation Limits for Categorizing Vegetation Communities in the Mojave Desert

Framework for understanding the effects of wildfire and climate change (Brooks and Matchett 2006, entire; Klinger *et al*. 2021, entire).

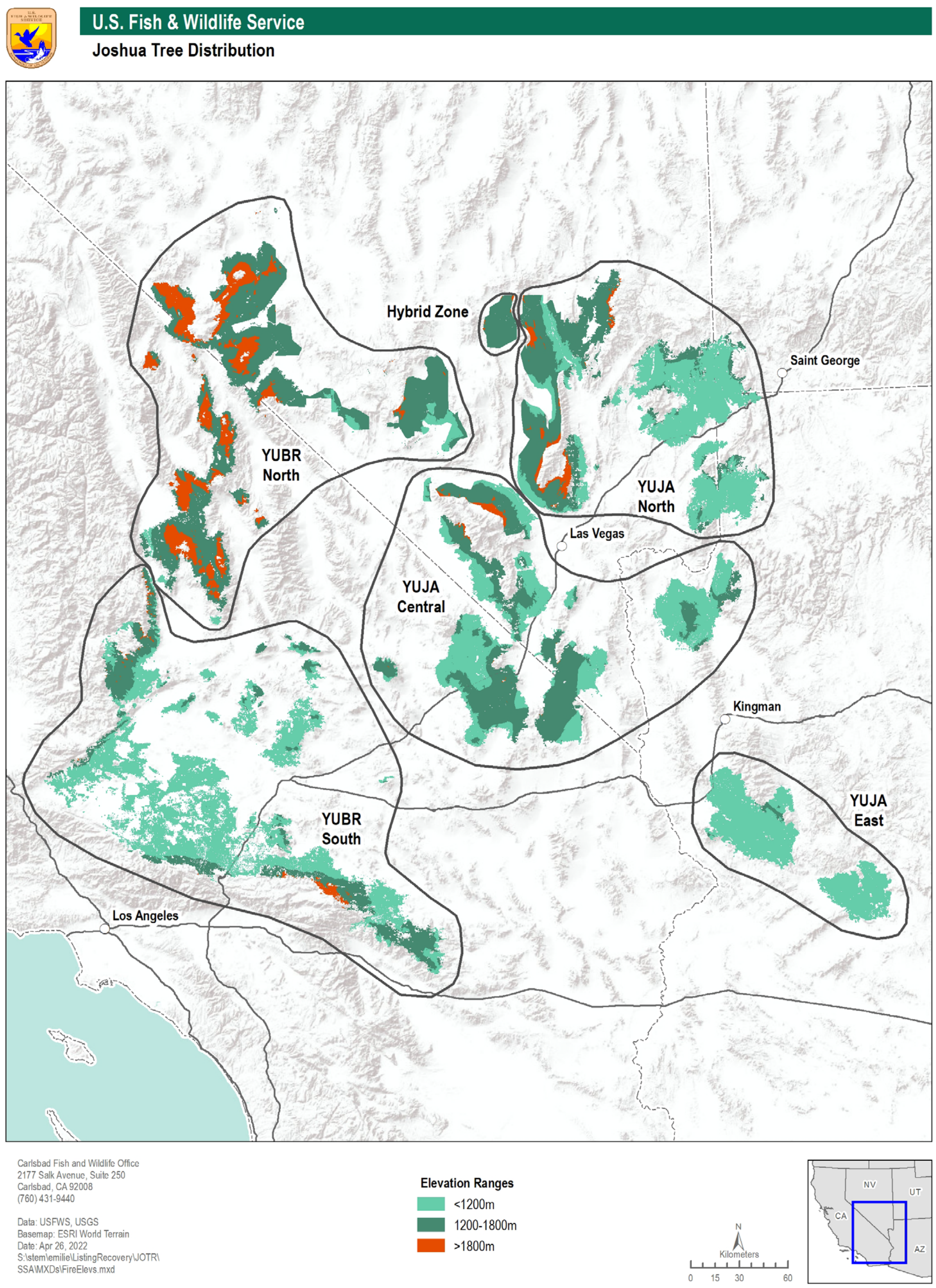

Figure D-1. Elevation ranges that correspond to low [less than 3,937ft (less than 1200m)], middle [3,937–5,905 ft (1200–1800m)], and high [greater than 5,905 ft (greater than 1800m)] elevation vegetation communities.

APPENDIX E

Mean Annual Precipitation by Analysis Unit

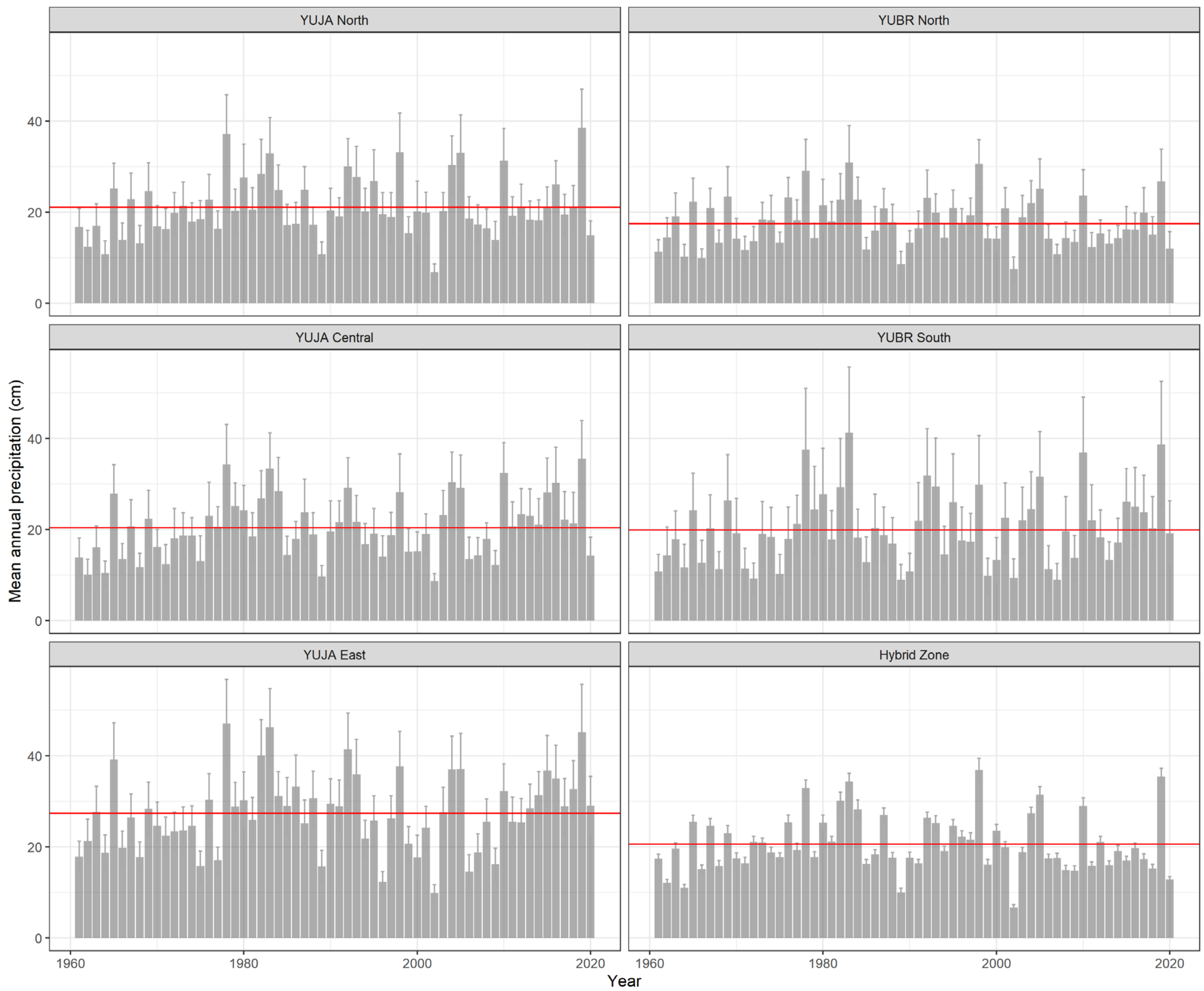

Figure E-1. Summary of mean annual precipitation (cm) by analysis unit.[6]

[6] Based on a random sample of 100 points. The range of values illustrated is based on the variability with the analysis unit and not the variability in temperatures during the period indicated. The historic period is from 1961-1990 and current period is 1991-2020 (Wang *et al.* 2016, unpaginated). The red line indicates the mean from 1960 to 2020.

APPENDIX F

Evaluation of Bioclimatic Modeling

Table F1. Summary of Bioclimatic Models Evaluated

Study	Study Area	Species	Analysis Scale	Method	Climate Parameters	Other Habitat or Species Parameters	Climate Models	Projected Timeframe	Low/Medium Emissions Scenario	Low/Medium Emissions Percent Decline	High Emissions Scenario	High Emissions Percent Decline
Thomas 2022b, pers. comm.	Range-wide	YUBR, YUJA combined	-	Maxent	-	-	CMIP5 CCSM4	2100	RCP 4.5	~44	RCP 8.5	~62
Sweet *et al*. 2019	JTNP + 5km	YUBR	270 m	Maxent	Climatic water deficit, annual precipitation, average minimum winter temp (Dec–Feb), average maximum temp (June–August)	Percent sand, slope, northness, eastness, ruggedness	CMIP5 MIROC	2070–2099	RCP 4.5	81.41	RCP 8.5	99.98
Comer *et al*. 2013	Mojave Basin and Range Ecoregion	Mojave Mid-Elevation Mixed Desert Scrub	4 km^2 (Ecoclim) and 15 km^2 (USGS) grid	Maxent	4 km^2: monthly maximum and minimum temperature, monthly total precipitation projections from Ecoclim for two future time slices (2020s and 2050s) compared to the 1950–1999 baseline from PRISM spatial climate data (Daly *et al*. 2002); 15 km^2: annual evapotranspiration, soil moisture, winter snow water equivalent, and soil runoff, and monthly maximum and minimum temperature and total precipitation for midcentury (2045–2060) compared to the 1968–1999 baseline all from USGS (Hostetler *et al*. 2011)	-	Ensemble mean of 6 GCMs (BCCR_BCM2_0, CSIRO_MK3_0, CSIRO_MK3_5, INMCM3_0, MIROC3_2_MEDRES, NCAR_CCSM3_0)	2060	-	-	A2	38
Barrows and Murphy-Mariscal 2012	JTNP + 10 km buffer	YUBR	200 m^2 grid (800 m for climate)	Mahalanobis distance statistic as multivariate index of habitat similarity	Max July temp., mean annual precipitation	Ruggedness, slope, northness, eastness, soil percent sand, soil water content	Created 11 scenarios (see reference Table 2) from combining 4 temperature scenarios (current, +1ºC, +2ºC, +3ºC) and 3 precipitation scenarios (no change, a 25 mm decrease in mean annual precipitation	undefined	"+1oC"; "+2oC"	30-35; 66-78	"+3oC"	90-98

Study	Study Area	Species	Analysis Scale	Method	Climate Parameters	Other Habitat or Species Parameters	Climate Models	Projected Timeframe	Low/Medium Emissions Scenario	Low/Medium Emissions Percent Decline	High Emissions Scenario	High Emissions Percent Decline
Thomas *et al*. 2012	Southwest, multiple species study	YUBR, YUJA combined	843.5 m^2 grid	Maxent	Average annual and monthly precipitation and temperature (minimum and maximum); total of 26 variables (1971–2000 as current)	-	Ensemble average of 16 GCMs, see reference Table 3	2050, 2100	B1; A1B	88.6; 84.8	A2	94.9
Cole *et al*. 2011	Range-wide	YUBR, YUJA combined	1 km & 4 km climate, 30-m topography	Probability surfaces using multiple logistic regression on presence/absence	2 best models: Model 2 (1 km) - highest (Feb) and lowest (Jan) monthly mean temperatures, mean monthly precipitation (April, June, August, Dec) over 20th century; Model 3 (4 km) - extreme mean monthly temperature (low-Feb/Dec; high-July/Nov) and mean monthly precipitation (Feb, April, May, June, August and Dec) from 1930–1969	Natural migration distance (2 km)	5 individual models (Hadgem1, Mpi-echam5, Csiro-mk3, Ncar-ccsm3, Cnrm-cm3) and 1 ensemble model from the Program for Climate Model Diagnosis and Intercomparison (PCMDI; AR4) archive	2070–2099	A1B	Up to 90	-	-
Dole *et al* 2003	Range-wide + 100 km buffer	YUBR, YUJA combined	10 km grid (1 km for temperature)	Nonparametric discriminant analysis	Jan, July, and annual precipitation, Jan average daily minimum temperature, July average daily maximum and average (1961–1990 as current); projected CO2	seedling freezing tolerance	Global Environmental and Ecological Simulation of Interactive Systems (Genesis) GCM	undefined	future climate with enhanced freezing tolerance	71	-	-
Shafer *et al* 2001	Rangewide, multiple species study	YUBR, YUJA combined	25 km grid	Response surfaces for probability of occurrence	Mean temperature of the coldest month, growing degree days, and a moisture index (1980–1989 as baseline)	-	HADCM2, CGCM1, and CSIRO	2090–2099	IPCC IS92a	Unquantified; > 80 percent		-

JTNP-Joshua Tree National Park.
CMIP5-Coupled Model Intercomparison Project 5

APPENDIX G

Bioclimatic Models

The following bioclimatic models were evaluated in our assessment of the potential effects of climate change on Joshua trees (Thomas *et al*. 2012, entire; Comer *et al*. 2013b, entire; and Cole *et al*. 2011, entire). We included the general results of these models for the future climate scenarios as described in section 8-1, with the exception of the data sent by K. Thomas, USGS (Thomas 2022b, pers. comm.). We had intended to utilize the available GIS data from these models to provide a more accurate assessment of the acreage of suitable and climatically unfavorable habitat at the scale of the analysis unit. However, we were unable to move forward with this approach due to inconsistencies between the distributions used in the various models and our current understanding of the species' distribution. For example, large portions of the current distribution were not modeled ranging from 6 percent (Thomas, In review) to 30 percent (Comer *et al*. 2013b, entire). Moreover, in one study (Thomas 2022b, pers. comm) a large portion (~46 percent) of Joshua trees occupied habitat was modeled as currently climatically unfavorable according to their modeled baseline distribution. To illustrate the issue, the following figures represent the modeled future distributions from these studies under the climate scenarios indicated, relative to our understanding of the current distribution of Joshua trees (indicated by the gray polygons).

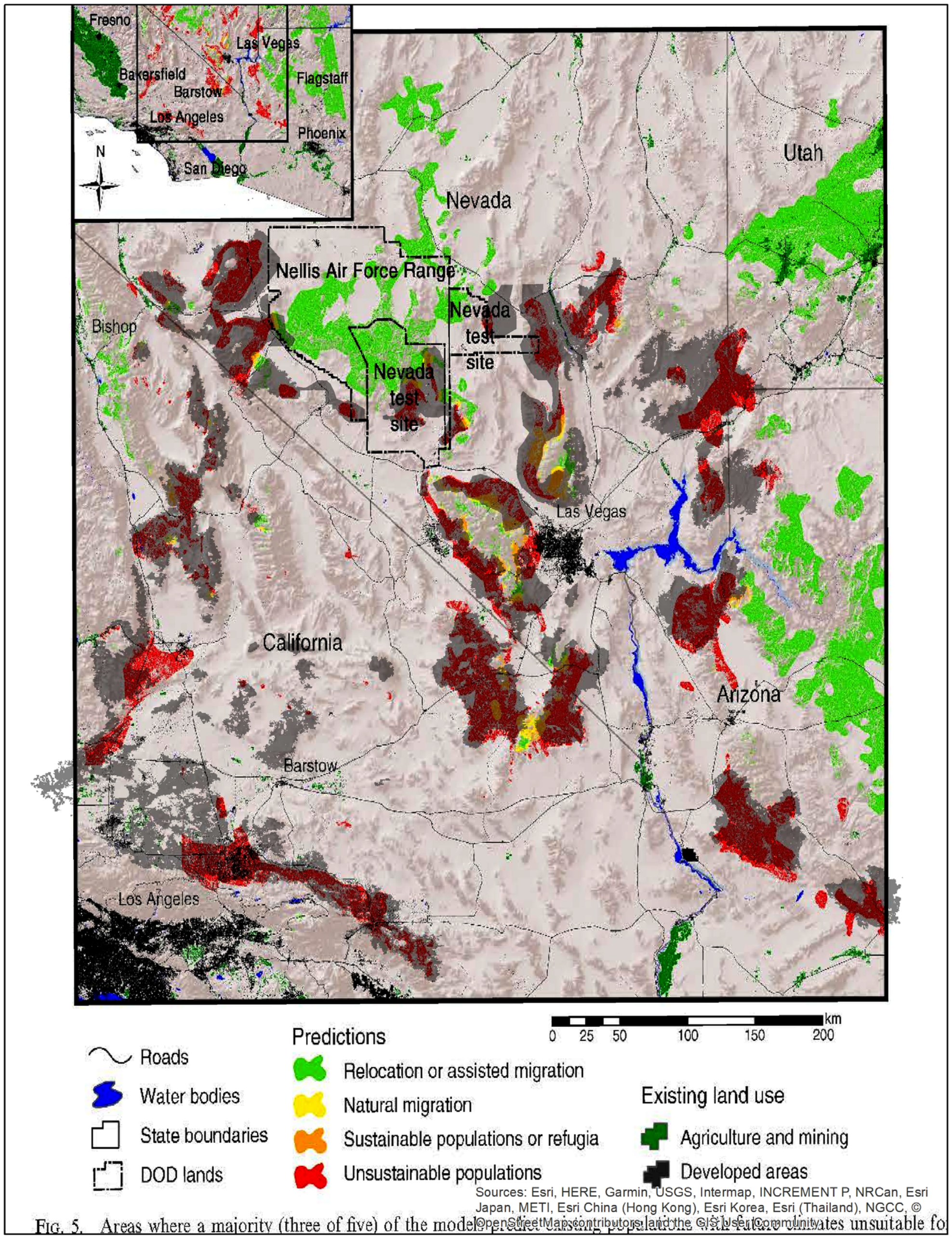

Figure G-1. Cole *et al.* (2011) illustrating a low to medium emission scenario under A1B for the period 2070–2099.

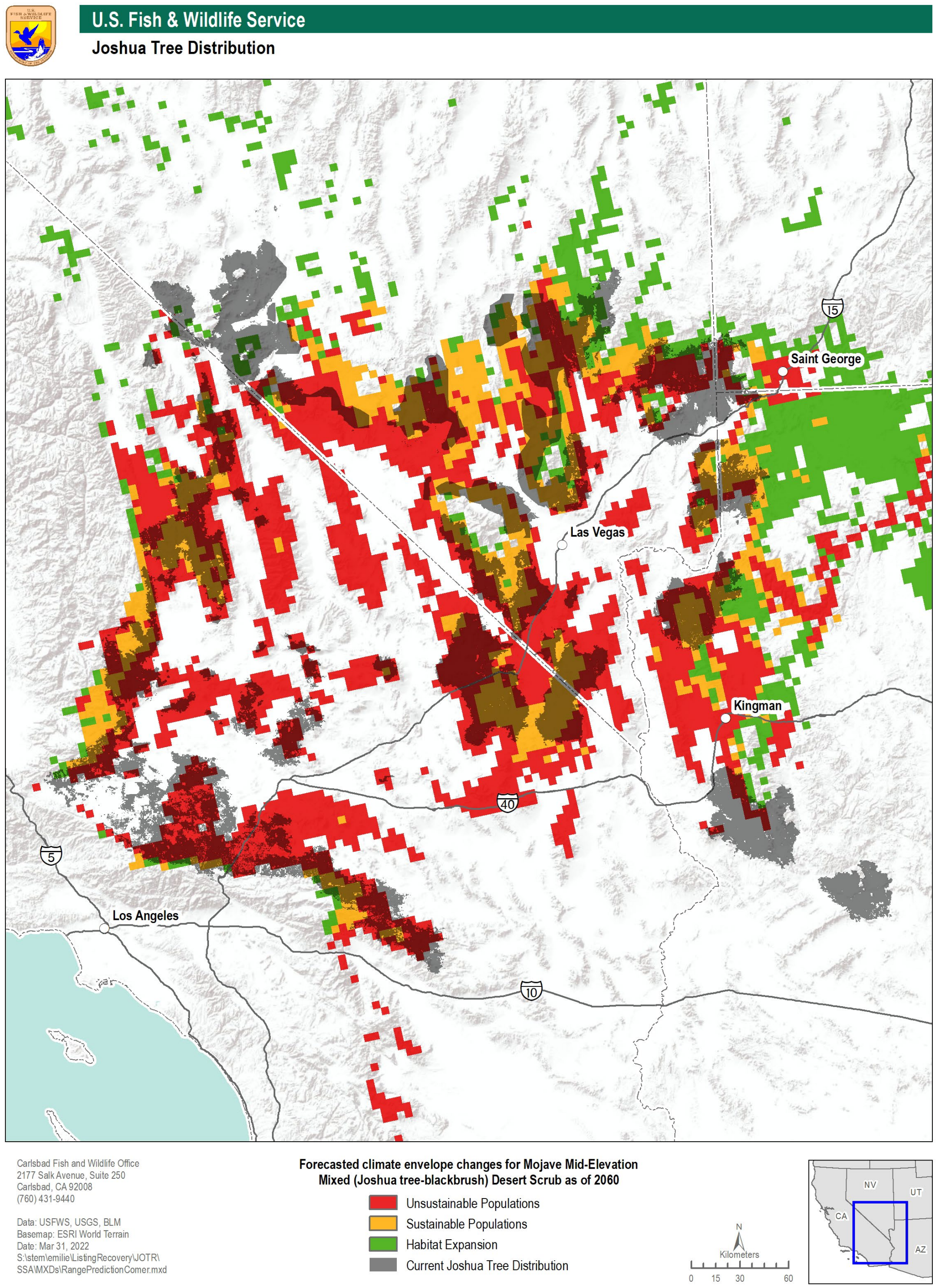

Figure G-2. Comer *et al.* (2013a) illustrating a high emission scenario under A2 for the period 2060.

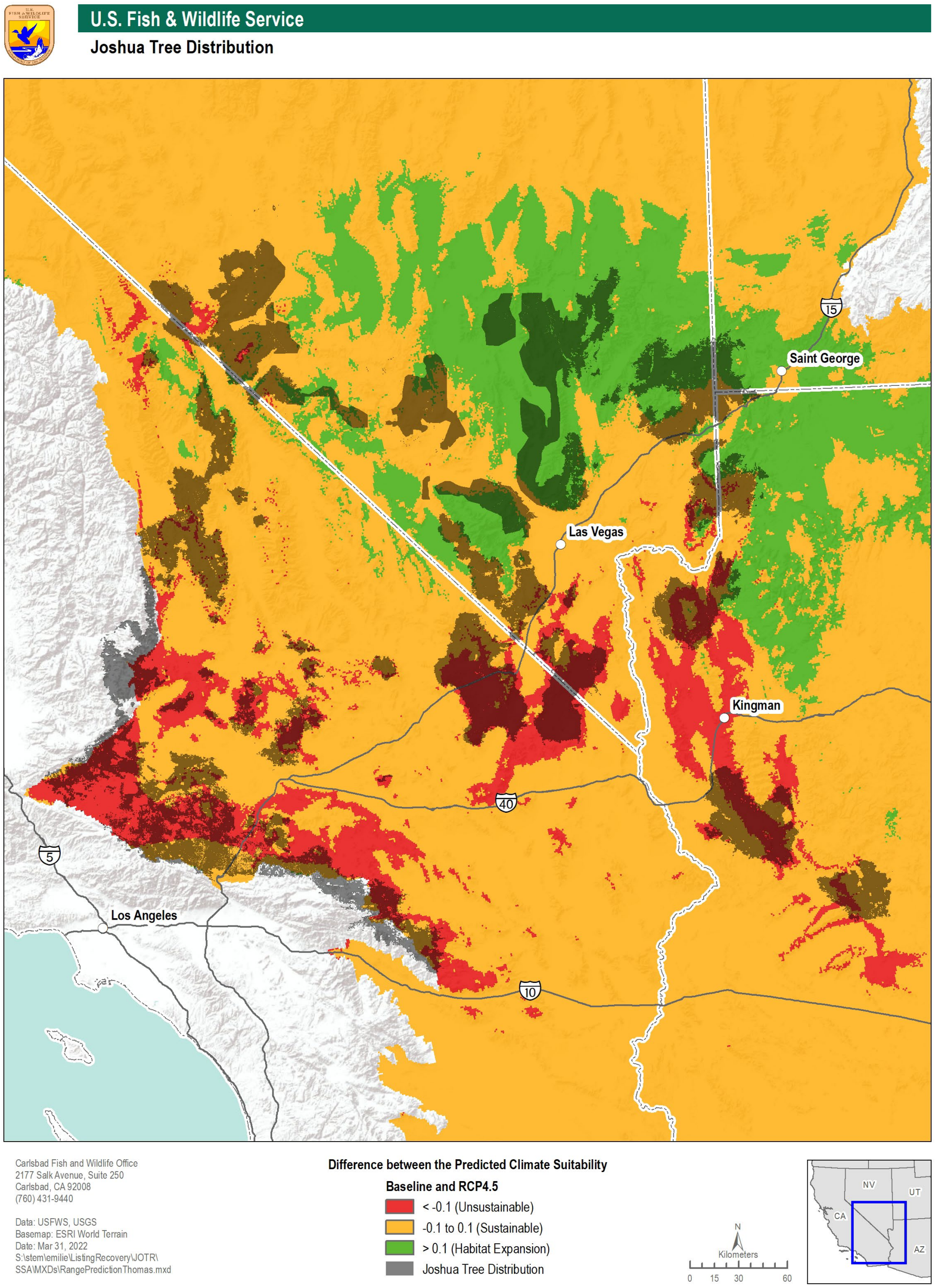

Figure G-3. Thomas (2022b, pers. comm.) illustrating a low emission scenario under RCP 4.5 for the period 2070–2099.

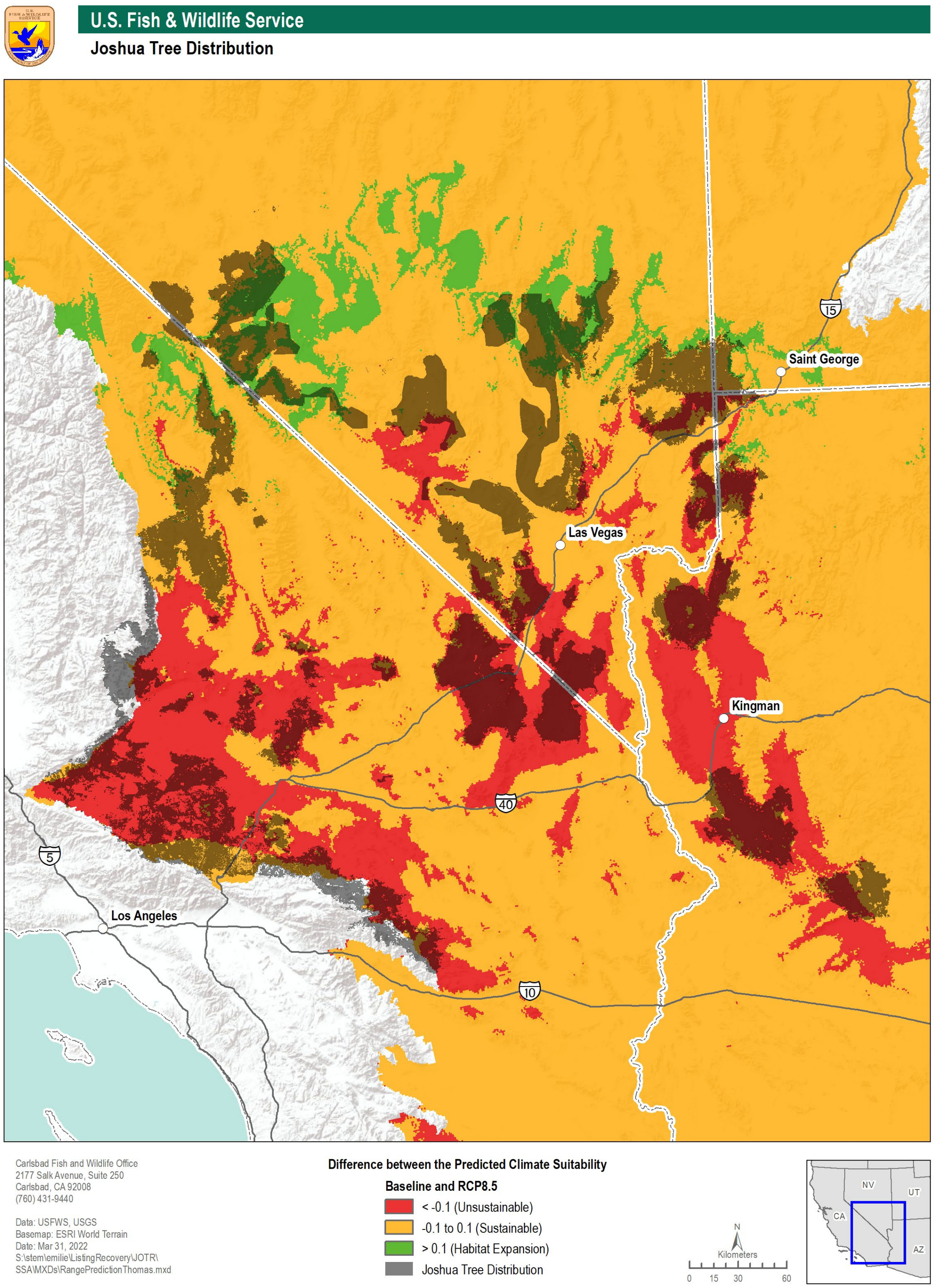

Figure G-4. Thomas (2022b, pers. comm.) illustrating a high emission scenario under RCP 8.5 for the period 2070–2099.