Species Status Assessment Report
for the
Giant Kangaroo Rat
(*Dipodomys ingens*)

Photo by Elizabeth Bainbridge

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EXECUTIVE SUMMARY

The U.S. Fish and Wildlife Service listed the giant kangaroo rat (*Dipodomys ingens*) as endangered under the Endangered Species Act in 1987 due to the threats of habitat loss and widespread rodenticide use (Service 1987, entire). The giant kangaroo rat is the largest species in the genus that contains all kangaroo rats. The giant kangaroo rat is found only in south-central California, on the western slopes of the San Joaquin Valley, the Carrizo and Elkhorn Plains, and the Cuyama Valley. The preferred habitat of the giant kangaroo rat is native, sloping annual grasslands with sparse vegetation (Grinnell, 1932; Williams, 1980).

This report summarizes the results of a species status assessment (SSA) that the U. S. Fish and Wildlife Service (Service) completed for the giant kangaroo rat. To assess the species' viability, we used the three conservation biology principles of resiliency, redundancy, and representation (together, the 3Rs). These principles rely on assessing the species at an individual, population, and species level to determine whether the species can persist into the future and avoid extinction by having multiple resilient populations distributed widely across its range. Giant kangaroo rats remain in fragmented habitat patches throughout their historical range. However, some areas where giant kangaroo rats once existed have not had documented occurrences for 30 years or more.

The giant kangaroo rat is found in six geographic areas (units), representing the northern, middle, and southern portions of the range. Geographic units are from the recovery units identified in the Recovery Plan for the species (Service 1998, p. 86). Land-cover, which is inhospitable to the giant kangaroo rat, separates some geographic units from one another, representing a barrier to dispersal for the species. Therefore, populations of giant kangaroo rats within the geographic units are genetically isolated. Data on long-term occupancy of these known sites suggest that giant kangaroo rats still have relatively high resiliency in the areas where they still occur, despite frequent and sometimes extreme population fluctuations.

We analyzed the needs of the giant kangaroo rat to assess the long-term viability of the species. This analysis revealed that several factors contribute to the current condition of the species. These factors, or stressors, include habitat modification or destruction, climatic variability, rodenticide use, inbreeding and genetic drift, invasive species, and wildfire. Under current conditions, we predict the giant kangaroo rat has one geographic unit in high condition, two in moderate condition, and three in low condition.

If giant kangaroo rat populations, or geographic units, lose resiliency, they are more vulnerable to extirpation, which results in losses of representation and redundancy for the species. The rate at which future stressors act on specific regions and the population-level impacts of current conservation actions are unknown. Therefore, we forecasted how possible future conditions could impact the resiliency, redundancy, representation, and overall condition of the giant kangaroo rat. To assess the future condition, we have developed three plausible future scenarios. The following is a description of these future scenarios:

In scenario 1, we assume there will be warm and wet conditions as described under climate change predictions. In this scenario, we predict that average annual temperatures and timing and duration of winter rains will increase. More rain in the summer months would increase non-native plant growth and result in giant kangaroo food caches to spoil. We assume urban and agricultural development will continue at current rates on unprotected lands. There will be limited opportunities for habitat

patches to increase in size, or for connectivity to increase or improve throughout the range. We assumed conservation efforts and restoration activities would remain the same as current levels.

In scenario 2, we assume there will be hot and dry conditions as described under high greenhouse gas concentrations and climate change predictions. In this scenario, hot and dry conditions will result in decreases in overall precipitation and an increase in drought intensity and duration. We assume that with hotter and drier conditions, there will be an increase in fallowed croplands across the historical range of the giant kangaroo rat. We presume that development from urbanization will continue at current rates on unprotected lands, with the potential to decrease habitat size and connectivity. Lastly, we assumed conservation efforts and restoration activities would remain the same as current levels.

In scenario 3, we assume there will be hot and dry conditions, similar to scenario 2 (above). We also predict there will be an increase in land protections in the central part of the species range, such that urban and agricultural development will slow and land protections will increase. We assume aggressive habitat restorations will take place on the fallowed croplands throughout the range of the species. Under these assumptions, connectivity and land protections will increase throughout the range.

Contents

CHAPTER 1. INTRODUCTION

This report summarizes the results of a Species Status Assessment (SSA) conducted by the US Fish and Wildlife Service (Service) for the giant kangaroo rat (*Dipodomys ingens*). The giant kangaroo rat is a federally and state endangered mammal, that occurs on the western slopes of the San Joaquin Valley, the Carrizo and Elkhorn Plains, and the Cuyama Valley in south-central California (Williams 1992, p. 307).

This Species Status Assessment (SSA) report is a summary of the information assembled and reviewed by the Service and incorporates the best scientific and commercial data available. We used the SSA framework to conduct an in-depth review of the species' biology and the stressors which impact the species. This information allowed us to evaluate its current biological status, and to predict the possible future status of resources and environmental conditions as a means of assessing the giant kangaroo rat's long-term survival. This SSA report summarizes the results of our analysis. This SSA will be updated when new species information becomes available. The SSA can support all functions of the endangered species program, including candidate assessments, listing decisions, consultations, and species recovery.

The purpose of this SSA report is to provide the biological and scientific support for a status review of the giant kangaroo rat, and as such, does not represent an opinion or decision by the Service. Instead, the document provides a review of the best available information related to the biological status of the giant kangaroo rat and provides the scientific analysis needed to support future decisions made by the Service.

Petition History and Previous Federal Actions

On December 30, 1982, the Service put forth a proposed rule, identifying the giant kangaroo rat as a taxon for which the Service had factual information to support the appropriateness of listing as endangered or threatened throughout its entire range (47 FR 58454). On August 13, 1985, the Service proposed to list the giant kangaroo rat as endangered (50 FR 32585). On January 5, 1987, the final rule designating the giant kangaroo rat was put forth by the Service (52 FR 283). The Service published the Recovery Plan for the species in 1998. There has been one 5-year review completed for the species in 2010, which outlined its current status at that time.

The Species Status Assessment (SSA) Framework

This SSA report summarizes the results of an in-depth review of the giant kangaroo rat's biology and stressors, an evaluation of the species' biological status, and an assessment of the resources and conditions needed to maintain long-term viability. For this assessment, we define viability as the ability of the species to sustain populations in the wild into the future in a biologically meaningful timeframe (For an explanation for our timeframes, see **Chapter 4. Future Condition**).

Using the SSA Framework (Figure 1), we consider what the giant kangaroo rat needs to be viable by characterizing the current and future status of the species using the concepts of resiliency, redundancy, and representation (the "3Rs") from conservation biology (Shaffer and Stein 2000, pp. 308–311; Service 2016, p. 12).

- *Resiliency* is the ability of populations to tolerate natural, annual variation in their environment and to recover from periodic or random disturbances, known as stochastic events. Resiliency can be measured using metrics like vital rates, such as annual births and deaths, and population size. In general, populations with high abundance and stable or increasing populations. Populations with high resiliency can better withstand the stochastic change in demography or their environment due to natural or anthropogenic disturbances.
- *Redundancy* is the ability of a species to withstand catastrophic events, such as a rare, destructive natural event that affects multiple populations. Redundancy is the duplication and distribution of populations across the range of the species. The more redundant a species or, the more significant number of populations a species has distributed over a broader landscape, the better able it is to recover from catastrophic events. Redundancy helps "spread the risk" across habitats and landscapes so that catastrophic events cannot extirpate all populations at once.
- *Representation* is the ability of a species to adapt to changing physical (climate or habitat) and biological (diseases, predators, etc.) conditions. Representation can be measured by looking at the genetic, morphological, behavioral, and ecological diversity within and between populations across a species' range. The more representation, or diversity, a species has, the more likely it is to adapt to and persist with natural or human-caused changes to its environment.

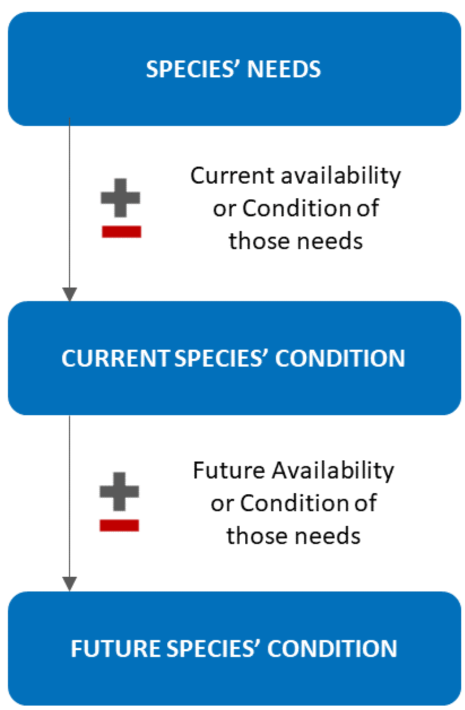


Figure 1. The three phases (blue boxes) of the SSA Framework used to guide this analysis. To assess the viability of the giant kangaroo rat, we evaluated the species' needs, the current availability and condition of those needs, and the species' current condition. We then predicted the species' future condition based on the future availability.

For the purpose of this SSA, viability is defined as the ability of a species to sustain populations in the wild over time. Viability is not a single state; rather, there are degrees of viability. In other words, we do not conclude that a species is or is not viable upon completion of an SSA. Instead, we characterize the resiliency, redundancy, and representation a species currently presents and predict how these characteristics might change into the future. Generally, species with greater resiliency, redundancy, and representation are more protected from the vagaries of the environment, can better tolerate stressors and adapt to changing conditions, and are thus more viable than species with low levels of the 3Rs.

To assess the viability of the giant kangaroo rat, we analyzed the species' ecology, historical and current conditions, and projected the viability of the species under a number of future scenarios, all in the context of the 3Rs and using the best scientific data available. Chapter 2 of this SSA report summarizes the biology, ecology, and needs of the giant kangaroo rat at the individual, population, and species level. Chapter 3 examines the stressors (and conservation measures) which impact the resiliency of giant kangaroo populations and analyzes the historical and current conditions of the species. Chapter 4 predicts the future condition of the species under three potential scenarios. In Chapter 5, we summarize all of the information presented in this SSA and analyze the viability of the giant kangaroo rat. In summary, this SSA is a scientific review of the best available information, including scientific literature and discussions with experts, related to the biology and conservation status of the giant kangaroo rat.

Summary of New Information

Since the completion of the 5-year review for the giant kangaroo rat in 2010, we reviewed new peer-reviewed literature and solicited data and new information from partner agencies within the state of California, including, but not limited to, state wildlife management agencies, universities, private contractors, and the Bureau of Land Management (BLM). Specifically, we requested new information (after 2010) on:

- The species' distribution, population sizes, population trends, and any updates to the species range or mapped colonies;
- The magnitude and severity of ongoing habitat loss;
- Other threats to the species including energy development, wildfire and rodenticide use;
- Updates to laws, regulations, or policies that might apply to the species; and
- Any ongoing conservation for the species and its habitats.

Our literature review and data solicitation resulted in new information on the genetic structure, population dynamics, and management and conservation efforts on state and BLM-managed public lands.

We incorporated these data, which include spatial data, peer-reviewed literature, reports, and personal communications, into various parts of the SSA, including the analysis of the current distribution of the giant kangaroo rat and the severity of stressor and related conservation actions. If we lacked specific data for some aspect of our analysis, we used information from other kangaroo rat species including the Heerman's kangaroo rat (*Dipodomys heermanii*), the California kangaroo rat (*Dipodomys californicus*), the San Joaquin valley kangaroo rat (*Dipodomys nitratoides*) and the banner-tailed Kangaroo rat (*Dipodomys spectabilis*).

CHAPTER 2. SPECIES ECOLOGY AND NEEDS

This chapter provides necessary biological information about the giant kangaroo rat, which includes its taxonomic history, relationships to other species, morphological description, physical environment, reproductive biology, and other life-history traits. We present the survival needs of the giant kangaroo rat at the individual, population, and species levels. This is not an exhaustive review of the species' natural history; instead, this section provides the ecological basis for the SSA report.

Life History

Taxonomy and Description

The giant kangaroo rat is a small, burrowing mammal that lives only in the central valley of California (Merriam 1904, p. 141). Kangaroo rats belong to the family Heteromyidae and are native to arid deserts and grasslands of North America (Genoways and Brown 1993, pp. 319–356; Alexander and Riddle 2005, p. 366). Heteromyid rodents have many adaptations to survive in dry environments (Grinnell 1932, p. 320; Alexander and Riddle 2005, p. 366). Kangaroo rats have physical and physiological adaptations to enhance water conservation, making them highly specialized in arid habitats (MacMillen 1983, pp. 65–68). There are more than twenty species kangaroo rats in the genus *Dipodomys*, of which the giant kangaroo rat is the largest (Merriam 1904, p. 139; Williams and Kilburn 1991, p. 1; Genoways and Brown 1993 pp. 319–356) (Table 1).

Mean Measurements (mm) of Giant Kangaroo Rats			
	Total Length	Tail Length	Hind Foot
Male	334.4	185.7	50
Female	332.9	181.2	50

Table 1. Mean measurements for male and female giant kangaroo rats. Males are generally larger than females (Grinnell 1932, p. 1).

Giant kangaroo rats can be distinguished from other large kangaroo rats by the presence of five, rather than four, toes on their hind feet (Grinnell 1922, p. 6). All kangaroo rats are adapted physically for bipedal, ricochetal locomotion; they are capable of moving quickly by hopping on their elongated hind limbs (Williams and Kilburn 1991, p. 2). In comparison, the forelimbs appear small, used mainly to collect seeds and grasses while foraging; enlarged claws on both front and back limbs aid in burrowing and self-defense (Williams and Kilburn 1991, p. 1).

The giant kangaroo rat has a proportionately large head, and a shortened neck, with the eyes and ears positioned high on the sides of the head (Williams and Kilburn 1991, p. 3). The tail makes up most of the length of the animal, being longer than the size of the head and body combined (Williams and Kilburn 1991, p. 1). Fur-lined cheek pouches open on either side of the mouth, forming deep, folded pockets along the head where the animal stores seeds while foraging (Grinnell 1932, p. 23). Giant kangaroo rats have counter-shaded fur. The back and head (dorsal side) is tan, with white or cream-colored underparts (ventral side). The tail has a black strip on top, ending in a large tuft of longer hairs (Grinnell 1922, p. 29; Williams and Kilburn 1991, p. 1). Juveniles can be distinguished from the adults by a light-gray dorsal coat, which becomes tan as the animal matures (Williams and Kilburn 1991, p. 1).

Habitat

Before European settlement, the San Joaquin Valley ecosystem was a mosaic of different habitats. Streams and rivers carried annual snowmelt from the nearby Sierra Nevada Mountains into large rivers. Riparian corridors followed river courses, bordered by seasonal wetlands that surrounded shallow lakes (Griggs *et al.* 1992, pp. 112–118). Outside of wetland areas, much of the southwestern San Joaquin Valley was desert-scrub with alkali-sink habitats (Germano *et al.* 2011, p. 139).

There are several species of kangaroo rats native to south-central California. These species are typically found in arid and semi-arid areas (Williams 1992, p. 301). Giant kangaroo rats occur in the San Joaquin Valley, the Carrizo and Elkhorn Plains, and the Cuyama Valley, where gently sloping hills and grasslands meet the coastal range of low mountains (Grinnell 1932, pp. 306–307). The scrub habitats were, and are, dominated by saltbush (*Atriplex spinifera* and *A. polycarpa*) as well as native and non-native annual grasses (Germano *et al.* 2011, p. 139).

The San Joaquin Valley experiences a Mediterranean climate (O'Farrell *et al.* 2016, p. 4). Winters are cool and mild, with high temperatures that remain above 10°C; low temperatures rarely reach freezing (Williams 1992, p. 302). The rain that does fall occurs during the winter months - between November and April (Williams and Kilburn 1991, p. 2). Summers are hot and dry, with midday temperatures that regularly exceed 38°C (Williams 1992, p. 302; O'Farrell *et al.* 2016, p. 4). The San Joaquin Valley receives little rain annually (<20 cm) (Williams and Kilburn 1991, p. 6).

Due to low amounts of annual rainfall and high summer temperatures, the western and southern portion of the San Joaquin Valley and adjacent valleys are considered a climatic desert (Germano *et al.* 2011, pp. 139–145). There are usually 6-8 months where no precipitation falls (Germano *in litt.* 2020). What little rain does fall, typically does so during the winter months. This influx of seasonal rainfall allows rich grasslands to form, which support a wide diversity of endemic plants and animals (Williams 1992, pp. 302–303).

Giant kangaroo rats have adaptations for life in arid environments such as the San Joaquin Desert. Distribution models for the species show that dry summers are essential for giant kangaroo rats to thrive (Bean *et al.* 2014, p. 6). Giant kangaroo rat abundance is highest in areas where there is no precipitation during the summer months (Bean *et al.* 2014, p. 6). However, as scatter hoarders (see *Feeding Habits* section below), these animals still rely on annual, primary productivity of forbs and grasses. Giant kangaroo rats are restricted to the driest portions of central California that also have high primary productivity or plant growth (Bean *in litt.* 2020). Researchers were more likely to detect giant kangaroo rats in areas where the summer months were extremely dry (receiving <4 millimeters (mm) of rain) and where average annual temperatures were between 14°C and 16°C (Bean *et al.* 2014, p. 6).

There is evidence that high rainfall years, or years when rainfall extends into the summer months, can be detrimental to the survival of giant kangaroo rats. Researchers attempting to relocate giant kangaroo rats on unoccupied habitat saw initial population growth for several years until the population crashed when the climate became wet (Germano, 2010, p. 86). When vegetation cover was high, researchers found that the abundance of giant kangaroo rats was also low. Residual dry matter (RDM) from high primary productivity (plant growth) was correlated with low population numbers (Germano and Saslaw 2017, p. 1624). An increase of associated herbaceous cover caused by too much rain and reduced food production in sequential dry years can both cause populations to crash, typical of the boom-and-bust population dynamics seen in desert rodent species (Germano and Saslaw 2017, p. 1624).

Optimal habitat for giant kangaroo rats is usually annual grassland communities with few or no shrubs on gentle slopes which do not flood in winter (Grinnell 1932, p. 306; Shaw 1934, p. 275; Hawbecker 1951, pp. 50–54; Williams *et al.* 1993, p. 9) (Figure 2). A few populations of giant kangaroo rats can be found in shrub communities, including the Elkhorn Plain, and can occur on slopes up to 22% in grade, but these areas are generally considered marginal habitat (Germano *in litt.* 2020; Williams 1992, p. 302; O'Farrell *et al.* 2016, p. 2). Researchers have recently found that slopes less than 5% facilitate the most dispersal and gene flow across the landscape (Alexander *et al.* 2019, p. 1533). Small, scattered populations of giant kangaroo rats can also occur atop hills and ridges, where slopes are flat enough (<10% slope), and soils are deep enough to allow for burrowing activity (O'Farrell *et al.* 2016, p. 10). Along with other native vertebrates, giant kangaroo rats are ill-equipped to survive in dense stands of non-native grasses, preferring more open, diverse plant communities (Germano *et al.* 2001, p. 550). These non-native grass species can also grow too tall for giant kangaroo rats to harvest seeds successfully. High rainfall encourages the growth of tall, non-native grasses (Cone 2008, p. 1). Marginal habitat does support limited numbers of giant kangaroo rats, but optimal habitat conditions support the largest, most abundant populations (O'Farrell *et al.* 2016, p. 10).

Figure 2. An example of giant kangaroo rat habitat within the Carrizo Plain National Monument. The image shows multiple burrow entrances conglomerated around a shallow mound, forming a classic precinct. Vegetation in the area is primarily sparse annual grasses and small forbs, both native and non-native. The area surrounding the burrow has been grazed and clipped by giant kangaroo rats, while larger grasses still stand off-site of the precinct. Habitat is on sandy-loam soils on gently sloping topography.

The soils of the San Joaquin Valley floor are alluvial or residual, which were formed from ancient marine sediment deposits and eroded from the surrounding mountains (O'Farrell *et al.* 2016, p. 4; Williams 1992, p. 302). Within low-slope areas, soils are predominantly sandy-loams, loams, and clay-loams (Nelson *et al.* 1921, pp. 35–39). In the Elk Hills region of Kern County, giant kangaroo rat burrows existed in a variety of soil series. Most soils were a fine, sandy-loam (O'Farrell *et al.* 2016, p. 10). The highest number and density of burrows were in Kimberlina and Tupman gravelly sandy-loam, both of which are deep (115-150 cm), well-draining soil types (O'Farrell *et al.* 2016, pp. 10–11; Williams 1992, p. 302).

The native plant community within the range of the giant kangaroo rat has changed since Europeans colonized California. Livestock, such as sheep and cattle, which overgrazed native plant communities, allowed exotic species of plants to take hold on the plains of the central valley (Williams 1992, p. 303). Within the Elk Hills area of their range, giant kangaroo rat habitat is in vegetative communities dominated by invasive Eurasian species including red brome (*Bromus rubens*) and red-stem filaree (*Erodium cicutarium*) (O'Farrell *et al.* 2016, p. 5). A list of plant species commonly found in giant kangaroo rat habitat is in Table 2.

Common Name	Scientific Name
Non-Native	
Oats	*Avena* spp.
Red Brome	*Bromus rubens*
Red-stem filaree	*Erodium cicutarium*
Arabian schismus	*Schismus arabicus*
Native	
Iodine bush	*Allenrolfea occidentalis*
Fiddleneck	*Amsinckia* sp.
Allscale	*Atriplex polycarpa*
Spiny Saltbush	*Atriplex spinifera*
California Ephedra	*Ephedra* sp.
California buckwheat	*Eriogonum fasciculatum*
Snakeweed	*Gutierrezia* sp.
Cheesebush	*Hymenoclea salsola*
Winter fat	*Krascheninnikovia lanata*

Table 2. These are common plant species that occur within giant kangaroo rat habitat. Where giant kangaroo rats exist, much of the native community has been altered due to non-native plant introductions by Europeans in the 1800s. Today, red-brome and red-stem filaree often dominate plant community composition. Still, many plants native to the San Joaquin Valley remain abundant (O'Farrell *et al.* 2016, p. 5; Williams *et al.* 1993, p. 9).

Feeding Habits

Giant kangaroo rats consume a variety of food resources, including seeds, invertebrates, and green plant material, the latter of which is usually only available in the spring (Grinnell 1932, p. 6; Shaw 1934, p. 276). Throughout most of the year, giant kangaroo rats primarily consume seeds, which they forage for with their small fore-limbs, and then transport in their fur-lined cheek pouches

(Williams and Kilburn 1991, p. 377; Williams *et al*. 1993, p. 10). Seeds not eaten immediately are cached in small pits near burrows, or taken back to the burrow itself (Shaw 1934, p. 277; Hawbecker 1951, p. 55; Williams *et al*. 1993, p. 10). Pregnant and lactating females have been found with the green matter in their cheek pouches, leading some to suggest early spring plant growth aids in reproduction and lactation (Grinnell 1932, p. 377).

Giant kangaroo rats cut the ripening heads of grasses and forbs (Shaw 1934, p. 275). These animals gather scattered seeds that blow to the ground and mix in the upper layer of soil (Shaw 1934, p. 277; Williams *et al*. 1993, p. 10). Seed species consumed include filaree (*Erodium*), peppergrass (*Lepidium nitidum*), fiddleneck (*Amsinckia douglasiana*), and brome (*Bromus rubens*), among many others (Shaw 1934, p. 275). Before moving seeds into underground caches or pits, all forage is dried in the sun, which prevents molding (Shaw 1934, p. 277; Williams *et al*. 1993, p. 10). During their lifetime, kangaroo rats rarely drink water, getting most of the moisture they need from the seeds and grasses which make up their diet (Williams and Kilburn 1991, p. 7).

Giant kangaroo rats are crepuscular, foraging on the surface during sunset and sunrise – although most activity takes place in the evening, during the first two hours after dark (Shaw 1934, p. 276; Braun 1985, p. 7). Annual activity patterns vary by season; foraging activity is highest in the spring as seeds of annual plants ripen (Service 1988, p. 88). The ability to transport large quantities of grains and other food in cheek pouches and their highly developed caching behaviors allow giant kangaroo rats to survive annual periods of drought (Williams *et al*. 1993, p. 11).

Burrowing Behavior

All species within the *Dipodomys* genus are solitary and live alone within their burrows (Cooper and Randall 2007, p. 1000). Giant kangaroo rats are territorial and defend seeds in a larder within their burrow. Each territory, or precinct, contains 2-4 burrow openings and a shallow underground system of complex tunnels (Cooper and Randall 2007, p. 1001). Although they live nearby to one another, animals within precincts are territorial and do not often share burrows or food resources with neighbors of the same species (Shaw 1934, p. 276; Murdock and Randall 2001, p. 152). Male and female giant kangaroo rats use smell to distinguish between individual neighbors (Murdock and Randall 2001, p. 152). All adults show high intraspecific aggression throughout most of the year (Eisenberg 1963a, p. 63; Murdock and Randall 2001, p. 153). Both males and females are territorial because their survival depends on building and defending seeds in a larder within their burrows, or in pit-caches near the burrow entrance (Randall 1997, pp. 1172–1173; Shaw 1934, p. 276).

Individual giant kangaroo rats will guard their seed caches against others who might try to steal their food (Eisenberg 1963a, p. 7). Each territory contains 2-4 burrow openings, and an underground system of elaborate tunnels and aboveground activity areas such as sand-bathing sites (Grinnell 1932, pp. 308–310; Shaw 1934, p. 276; Cooper and Randall 2007, p. 1001). Male and female giant kangaroo rats show differences in home-range partitioning throughout the year; the size of home ranges varied seasonally for males but not for females (Cooper and Randall 2007, pp. 1003–1005).

Kangaroo rats are fossorial, spending the majority of time underground to avoid hot, daytime temperatures, emerging for only a few moments to forage after dusk (Braun 1985, p. 7). Because of this behavior, these animals can only occur in habitats with specific soil composition, which allows for stable, deep burrows to be built (O'Farrell *et al*. 2016, p. 2). Giant kangaroo rat burrows have multiple, horizontal entrances within a circular, mounded area, vertical holes approximately 5 centimeters (cm) in diameter, which they sometimes plug with soil, and 'haystacks' of clipped, annual grass seed heads in the vicinity of the mound (O'Farrell *et al.* 2016, p. 6).

Dispersal

Maximum dispersal distance for giant kangaroo rats has been estimated as 2.25 kilometers (km) based on documentation of sibling individuals found 5.5 km from one another (Alexander *et al.* 2019, p. 1539-1540). These long-distance dispersal events appear to be uncommon, and other researchers have found that individuals are more likely to disperse 700 meters (m) from their natal den (Loew *et al.* 2005, p. 496), suggesting that giant kangaroo rats are generally philopatric. It appears that while giant kangaroo rats have strong habitat preferences, they are more generalized during dispersal events (Alexander *et al.* 2019, p. 1541). It is potentially possible for giant kangaroo rats to pass through high-slope or inappropriate habitat to get to a new area with suitable habitat; however, suitable habitat allows for greater dispersal and gene flow across the landscape (Statham *in litt.* 2019). Habitat suitability models show that low annual precipitation and low slope allow for more gene flow (Alexander *et al.* 2019, p. 1541) and habitat connectivity is needed for populations to have adequate gene flow across the landscape.

Life Cycle and Reproduction

The giant kangaroo rat has an adaptable reproductive pattern that is affected by both population density and environmental conditions (Service 1998, p. 88) (Figure 3). Breeding occurs annually, or bi-annually, depending on available resources, usually between January and May, and extending into July and August during some years (Randall *et al.* 2002, p. 16; Williams and Kilburn 1991, p. 377; Bean *in litt.* 2020) (Figure 3). In highly productive seasons, giant kangaroo rats can breed during the year of their birth, and mature females may mate twice (Service 1998, p. 88).

Observations on mating suggest that males visit the burrows of females during the winter breeding season (Randall *et al.* 2002, p. 15). In other species of kangaroo rat, males have been observed to den with females during estrus, at which time mating likely occurs (Eisenberg 1963b, p. 62). Mating behavior varies with population density, the number of females in estrus, and the operational sex ratio (Randall *et al.* 2002, p. 18; Cooper and Randall 2007, p. 1005). In years with relatively high densities and skewed sex ratios, multiple males compete for access to females; in contrast, during low-density years, each male appeared to mate with a single female neighbor (Cooper and Randall 2007, p. 1006).

For large species of kangaroo rats, such as the giant kangaroo rat, gestation lasts between 29 and 34 days (Eisenberg 1963b, p. 63). Females usually give birth to litters of one or two pups at a time, but can have more (Randall *et al.* 2002, p. 16). Kangaroo rat pups are born blind and hairless, and remain so until after the first two weeks of life (Reynolds 1958, p. 114). By 3 or 4 weeks of age, the mother will ween the young (Reynolds 1958, p. 114). Dispersal happens soon after the young emerge from the natal den, when either the mother, siblings, or both chase them off (Service 1998, p. 88). Many individuals do not appear to live past 18 months of age. However, some individuals can live up to 4-5 years (Germano and Saslaw 2017, p. 1623; Germano *in litt.* 2020). There is evidence of some individuals living up to six years on study plots in the Carrizo plain (Bean *in litt.* 2020).

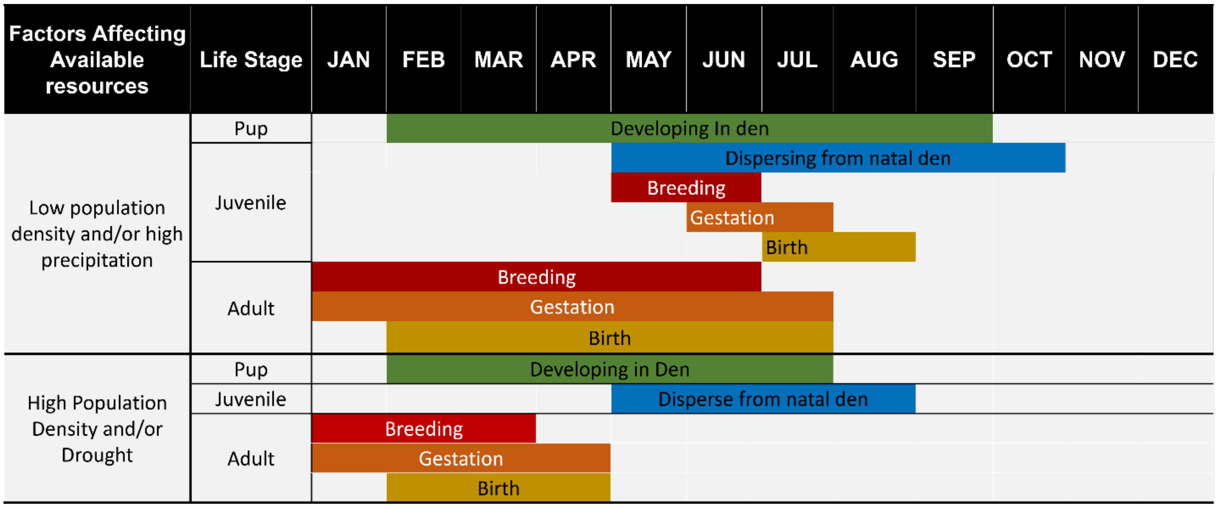


Figure 3. Gant timeline-chart for annual life cycle of a giant kangaroo rat adult, pup, and juvenile. Life cycles vary for individuals depending on various factors which affect available resources. During years of drought, females only give birth once annually and the juveniles do not breed. During years of normal to high rainfall, one female can sustain multiple litters and juveniles might breed successfully. Local population density can also affect the breeding rates of individuals in similar ways.

Metapopulation dynamics

In the northern portion of their range, giant kangaroo rats occur on patches of optimal habitat in demographically distinct populations in discrete locations, which are difficult to identify due to annual population fluctuations (Statham *et al.* 2019, p. 8; San Joaquin Valley Upland Species SSA: Expert elicitation meeting 2019). Fluctuating population numbers are due in part to climatic conditions and annual plant production. Giant kangaroo rats only inhabit marginal habitat during highly productive years (San Joaquin Valley Upland Species SSA: Expert Elicitation Meeting 2019). Some habitat patches within geographical units support populations with growth rates that encourage emigration, while other habitat patches are less favorable (San Joaquin Valley Upland Species SSA: Expert Elicitation Meeting 2019). Past reports have documented the disappearance of colonies within the Panoche region, which have since been recolonized when conditions allowed (Williams *et al.* 1995, pp. 3–6). These source-sink dynamics are characteristic of metapopulations, which often have a finite lifetime, and are prone to local extinction (Hanski, 1991, p. 4). Within some areas of the range, there is genetic evidence of source-sink dynamics and genetic drift across the landscape, which supports the metapopulation hypothesis (Statham *et al.* 2019, p. 8) (see 'Genetic Diversity and Range partitioning' below). Within the southern portion of the range, giant kangaroo rats exist as a large, continuous population across much of the Carrizo Plain and surrounding areas (Statham *in litt.* 2020).

Genetic Diversity and Range Partitioning

A goal of this SSA report is to identify evolutionary potential by managing populations that preserve the full spectrum of species diversity (i.e., redundancy) across the species' range. Genetic studies have found evidence of two, geographically distinct, portions of the historical range of giant kangaroo rat, which correspond to the northern and southern portions of the species' range (Good *et al.* 1997, p. 1308). The northern portion of the historical range of giant kangaroo rat is equivalent to the Panoche geographic unit. Within the Panoche, giant kangaroo rats exist as a metapopulation, comprised of many subpopulations with varying degrees of gene flow across the landscapes (Statham *et al.* 2019, p. 8). The southern portion of the historical range incorporates the Carrizo Plain and Western Kern county geographic units. The Cuyama Valley populations are probably genetically related to populations on the Carrizo Plain, but there is no genetic data from this region (Statham *in litt.* 2020). Populations in the San Joaquin Valley might be a distinct metapopulation from the Carrizo Plain metapopulation. The Temblor Mountains are a natural feature separating these two areas and are likely an effective barrier to significant dispersal (Blackhawk *et al.* 2016, p. 272).

The northern and southern portions of the historical range appear to have diverged between two thousand to thirteen thousand years ago (Statham *et al.* 2019, p. 7). The two regions likely represent peripheral segments of a much larger historical population (Statham *in litt.* 2020). Subpopulations within the northern metapopulation appear to show some signature of genetic drift which is characteristic of small, localized populations. Genetic analyses of migration rates suggest there are source-sink dynamics, and identified the large centrally located Tumey Hills population as a source population (see metapopulation dynamics above) (Statham *et al.* 2019, p. 7). Researchers have acknowledged that gene flow across the landscape might change depending on the timeframe of the study. Statham *et al.* (2019) had different results than Loew *et al.* (2005). Both concluded that there was movement between the subpopulations within the Panoche region, but that the movement would change depending on local environmental conditions. Additionally, the topographic diversity of the region maintains genetic diversity in the Ciervo-Panoche geographic unit (Good *et al.* 1997, p. 1307).

The northern and southern portions of the giant kangaroo rat historical range are spatially and genetically disjunct and separated by approximately 150 km. These populations represent the northern and southernmost range limits and, as such, represent geographically distant peripheral segments of a once more extensive range (Good *et al.* 1997, p. 1307). Genetic studies have shown a high level of genetic diversity still exists throughout the range of the giant kangaroo rat, despite population fluctuations (Good *et al.* 1997, pp. 1306–1307; Statham *et al.* 2019, p. 8). Genetic diversity in both the northern and southern parts of the range increases redundancy for the giant kangaroo rat. Genetic analysis of both the northern and southern portions of the historical range shows declines in effective population size after European colonization and land-use changes in the central valley (Statham *et al.* 2019, p. 7). It is unknown how much diversity was lost due to habitat loss throughout the species' range as a result of human land-use changes (Good *et al.* 1997, pp. 1308–1309). Conservation of current genetic diversity remains and important objective for long-term species viability.

Ecosystem-scale Contributions

Giant kangaroo rat burrowing activities modify the surface topography of the landscape and change the mineral composition of the soil (Service 1998, p. ix). Where present, the giant kangaroo rat occurs in such abundance that their burrowing activity can change the habitat composition (Shaw 1934, p. 2; Prugh and Brashares 2012, entire). The precincts of the giant kangaroo rat are visible on satellite images, and can alter the community composition of the local vegetation (Cone 2008, p. 1; Semerdjian 2019, p. 7; Prugh and Brashares 2012, p. 671). Many plants grow on the soil disturbed by giant kangaroo rats as they burrow (Service 1998, p. 91). The California jewelflower (*Caulanthus californicus*), a federally endangered plant, is one of several species that grow on burrow systems (Service 1998, p. 89) and native plants growing on giant kangaroo rat precincts appear to be more robust and healthy (Service 1998, p. 91). Other species occupying the burrows of giant kangaroo rats include the blunt-nosed leopard lizard (*Gambelia sila*) and the San Joaquin antelope squirrel (*Ammospermophilus nelsi*), along with many species of invertebrate animals (Goldingay *et al*. 1997 p. 49). When abundant at a site, giant kangaroo rats are essential prey items for many predators, such as the federally endangered San Joaquin kit fox (*Vulpes macrotis mutica*), making them an important part of the ecological food chain (Service 1998, p. 91).

Giant Kangaroo Rat Needs

All species have ecological needs. Whether these needs are fulfilled determines if a species will survive or thrive. In this section, we translate our knowledge of the giant kangaroo rat's biology and ecology into needs. We do this at the level of the individual animal, the local population, and finally for the entire species. For individual giant kangaroo rats, we describe the habitat resources and conditions needed for pups, juveniles, and adults to complete the stages of their life cycle. We then describe the habitat and demographic conditions that giant kangaroo rat populations need to be resilient. Finally, we explain what the species needs to be viable in terms of resiliency, redundancy, and representation (Table 3).

Individual Needs

Individual needs for the giant kangaroo rat vary by life stage (Figure 4). The pups are born underground in burrows in the spring or summer (Grinnell 1932, p. 314; Bean *in litt*. 2020). For pups to survive this life stage, females need access to friable soils, deep enough to build safe burrows for the young. In average rainfall years, water does not penetrate the ground far enough to flood the burrows or spoil seed stores. Adequate vegetation is essential for females to provide enough milk for the young to develop during this time. Young are born during the short rainy season in the San Joaquin Valley, which triggers rapid vegetation growth. Researchers have observed that females consume large amounts of green vegetation in early spring, which helps to offset the energetic cost of feeding young (Grinnell 1932, p. 313).

Once the young emerge from the burrows, they must find territories of appropriate habitat. The primary time for dispersal seems to follow maturation at around 12 weeks of age (Service 1998, p. 89). In years of high population density or low food resources, young appear to stay near their natal burrow until they are driven off by the mother or littermates (Service 1998, p. 89). Males and females exhibit different dispersal behaviors, with males dispersing much farther than females (Service 1998, p. 89). Based on capture-mark/recapture data, male giant kangaroo rats on average, dispersed up to 122 m and females 99 m; rarely, individuals disperse distances of over 700 m (Loew *et al*. 2005, p. 496). However, genetic studies have found siblings in territories 5 km apart, suggesting that individuals can disperse much greater distances on rare occasions (Alexander 2016, p. 16). Because of their limited dispersal capabilities across unsuitable habitat, habitat connectivity is essential for giant kangaroo rat viability.

Habitats of the giant kangaroo rat are typically grassland-dominated landscapes on sandy-loam soils, which are not subject to frequent flooding (Loew *et al*. 2005, p. 496). Being primarily granivorous (Williams and Kilburn, p. 377), adult giant kangaroo rats need abundant seed resources to survive (Shaw 1934, p. 282). Although they feed on green plant material and invertebrates (Grinnell 1932, p. 23), giant kangaroo rats primarily collect and store seeds, which sustain them throughout the hot, dry summers in the San Joaquin Valley (Williams 1992, p. 302). Therefore, seeds are the primary food resource needed by the species.

In addition to the other resources needed at early life stages, adult giant kangaroo rats need mates. Once they have established a territory, they do not move far from their burrows during their adult lifespan (Braun 1985, p. 8), suggesting they do not move large distances in search of mates. Therefore, giant kangaroo rats need to have overlapping territories with individuals of the opposite sex. Studies show there is no significant difference in the size of male and female home ranges (Braun 1985, p.10; Cooper and Randall 2007, p. 1003). Thus, habitat requirements for adults are likely the same between sexes throughout the majority of the year. During the winter breeding season, males are more likely to overlap with females; females rarely overlap with other females during the breeding season (Cooper and Randall 2007 p. 1003).

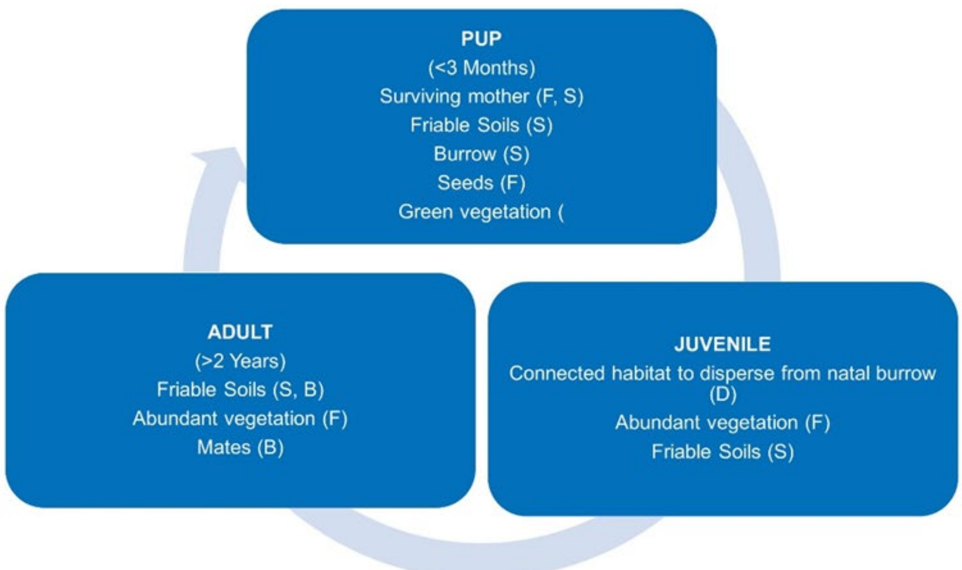


Figure 4. Life cycle diagram with the resource needs for individual giant kangaroo rats - pups, juveniles, and adults. Every need fulfills an aspect of the stage in the life cycle, shown in parentheses. Individual giant kangaroo rats need these resources to breed (B), feed (F), shelter (S), and disperse (D).

Population Needs

For this SSA, we define a giant kangaroo rat population as a complex of precincts within dispersal distance of one another (<5 km) on appropriate habitat with a high degree of connectivity. Habitat within the range of the giant kangaroo rat has mostly been converted to agriculture, fragmenting much the historical range for the giant kangaroo rat, and isolating existing populations from one another. Highly connected habitats still have the largest, most robust populations of giant kangaroo rats. As such, contiguous habitats appear to be essential for long-term species' survival. Populations likely need habitat patches of an appropriate size to persist over time.

In its evolutionary past, the giant kangaroo rat has experienced annual cycles of drought and rainfall, typical of a Mediterranean environment. However, under current climate change scenarios, climatic variability in the San Joaquin Valley is likely to increase. The San Joaquin Valley will likely see prolonged periods of drought (5 years or longer) punctuated by uncharacteristically heavy rainfall events. Individual giant kangaroo rats will need to move throughout the environment to find enough mates and resources to survive and reproduce during times of drought and increased temperatures. Therefore, areas of contiguous habitat are needed to ensure the species can survive harsh conditions.

The relationship between droughts, precipitation, herbaceous growth, and population change is complicated (Germano *in litt.* 2020). For most nocturnal rodent communities in arid ecosystems, precipitation and subsequent herbaceous plant productivity influence population abundance (Germano and Saslaw 2017, p. 1623). Heavy precipitation might induce annual population changes in giant kangaroo rat populations. Although the direct effect on individuals is unclear, studies have shown that populations of giant kangaroo rats decline during winters with above average rainfall (Single *et al.* 1996, pp. 34–40). Germano and Saslaw (2017) found that precipitation following a drought saw abundance of giant kangaroo rats increase (p. 1624). However, they did caution that when primary productivity causes dense foliage to persist into the summer, it might cause seed spoilage, and subsequent population declines (Germano and Saslaw 2017, p. 1624).

Studies on other species of kangaroo rats also suggest that populations respond negatively to heavy-rainfall years. Banner tailed kangaroo rats (*Dipodomys spectabilis*), a large kangaroo rat species from Arizona, exhibited steep declines in population numbers during wet, El Niño years with high precipitation (Valone *et al.* 1995, p. 430). While the reason for declining kangaroo rat populations during wet years is still unclear, researchers have hypothesized that seed caches spoil and animals eventually starve or suffer from mold-toxins, which result from moisture in seed caches (Valone *et al.* 1995, p. 430). Still, others suggest that wet years spur changes in vegetation composition, which can have a cascading effect on the ecosystem, ultimately causing a decline in the seed-producing grasses which kangaroo rats need to survive (Waster and Ayers 2003, p. 1038). Giant kangaroo rat populations have seen similar population fluctuations throughout periods of drought and wet years (Prugh *et al.* 2018, pp. 1–5). For the species to survive, average rainfall years, where precipitation does not fall in the summer months (when seeds are dried and cached), are needed for long term persistence of the species. Conversely, prolonged droughts also reduce abundance, suggesting there is a minimum precipitation amount needed for population viability, although no research exists to determine what amount that might be.

Large tracts of habitat, with a variety of microclimates and local population connectivity, can help mitigate the effects of climatic stress to the species by increasing the survival of individuals and allowing for population recruitment from other areas. Habitat connectivity between subpopulations is needed for gene flow between populations.

Species Needs

As a species, the giant kangaroo rat needs multiple, resilient, connected populations that display genetic diversity across its range and a suitable annual climate (Service 1998, p. 89; Germano *et al.* 2001, p. 553). Currently, there is still a high degree of genetic diversity within all populations. However, these populations exist in small, isolated areas of habitat across the range (Statham *et al.* 2019, p. 8). Populations with these characteristics are more prone to genetic drift, which leads to loss of diversity over time, and, possibly, inbreeding depression and extinction. Maintaining genetic diversity is an important factor for the species to persist into the future in response to changing climatic variables or stochastic events.

Species distribution models suggest the strongest predictors of giant kangaroo rat presence are areas where the driest month received a mean of 0 mm of precipitation (Bean *et al.* 2014, p. 6). The species exists within a narrow range of climatic conditions, increased amounts of summer rainfall could hinder the species' long-term viability.

Although once widespread and abundant, giant kangaroo rat habitat has decreased dramatically, due mainly to industrialized agriculture (Blackhawk *et al.* 2016, p. 261; Williams and Kilburn 1991, p. 3) and habitat fragmentation, which can be detrimental to the survival of the species (Blackhawk *et al.*, p. 263). Currently, the six remaining analysis units of giant kangaroo rat are highly fragmented, and there is little chance of migration and gene flow across the range of the species (Service 2010, p. 87) (Figure 6). Giant kangaroo rats do not disperse far, nor do they move once they have established adult territories. Habitat connectivity is an important need for persistent giant kangaroo rat populations.

Summary of the Species Needs in Terms of the 3Rs

When individual giant kangaroo rats have access to seeds, friable soils, adequate habitat, suitable climatic conditions, and access to mates throughout the year, reproductive rates increase, and precincts multiply (Loew *et al.* 2005, p. 496; Shaw 1934, p. 282; Williams and Kilburn 1991, p. 3). These conditions create resilient populations that can withstand periodic natural disturbances, such as prolonged winter droughts, massive rainfall events, or wildfires (resiliency). At the population level, giant kangaroo rat juvenile survival and dispersal drive annual population growth (Germano and Saslaw 2017, p. 1624). Genetic diversity is needed for the species to adapt to changing physical and ecological conditions (representation) and maintain a wide distribution of resilient populations across its range (redundancy). Contiguous habitat is needed to allow for gene flow across the species' range (Germano and Saslaw 2017, p. 1625). With many colonies spread across geographical units within the range and a high potential for migration within these areas, populations are better able to withstand catastrophic events (redundancy) (Germano and Saslaw 2017, p. 1625). At the species level, habitat connectivity facilitates a network of multiple (redundant), self-sustaining (resilient) populations distributed across the range of the giant kangaroo rat, which display the breadth of their genetic and ecological diversity (representation). Representation increases the ability of the species to adapt to changing physical and biological conditions (Table 3).

Level	Need	Function of Need	Association with the 3Rs
Individual	Friable Soils,	Digging burrows, caches, and larders to store food and escape from predators	Resiliency
	Seeds	Maintain food resources through cyclical dry periods; water resources	Resiliency
	Appropriate Habitat	Habitat for dispersing individuals	Resiliently, Redundancy
	Abundant vegetation	Meet caloric and nutritional needs during the breeding and pupping season; increase seed production to facilitate seed storage and caching	Resiliency
	Access to Mates	Reproduction; Fecundity	Resiliency
Population	Individual Survival	Increase population growth	Resiliency
	Habitat Connectivity for Dispersal	Increase genetic diversity, allows for immigration following catastrophic events, increase the abundance within populations and the number of populations across the range	Resiliency, Redundancy
Species	Connected populations across the range	Improves the viability of the by reducing risks posed by catastrophic events	Redundancy
	Maintain genetic and ecological diversity throughout the range of the species	Preserves diversity and provides for adaptability in the face of changing environmental conditions	Representation

Table 1. Summary of individual, population, and species' needs for the giant kangaroo rat in terms of the 3Rs.

CHAPTER 3: CURRENT AND HISTORICAL CONDITION

This chapter summarizes the historical and current conditions of the giant kangaroo rat for an individual, a population, and the species as a whole. We do this by introducing stressors, sometimes synonymous with threats, which historically influenced and continue to influence the species' condition, in addition to current conservation efforts. We then detail how the abundance of giant kangaroo rats has changed over time. Finally, we put the species' historical and current conditions in the context of redundancy, resiliency, and representation to assess the ongoing viability of the species.

The giant kangaroo rat's historical range extends along the western side the San Joaquin Valley and inner-coastal ranges, within the state of California (Figure 5). Before European settlement, giant kangaroo rats existed on thousands of acres of continuous habitat (Service 1998, p. 85). This range stretched from the base of the Tehachapi Mountains in the south to Merced County, in the north. The western boundary of the range includes the Carrizo Valley, the Elkhorn Plains, and the San Juan Creek watershed west of the Temblor Mountains. The upper Cuyama Valley is nearly adjacent to the Carrizo Plain and the Kettleman Hills exist within the San Joaquin Valley. Other colonies exist on steeper slopes and ridge tops in the Ciervo, Ciervo-Panoche, and Tumey Hills in the Panoche Valley (Service 1998, p. 85).

Data Use Statement

For this SSA we compiled spatial data from the International Union for Conservation of Nature (IUCN 2019), the California Natural Diversity Database (CNDDB 2019), California Conservation Easement Database (2019), California Protected Areas Database (2019) and data provided by researchers (Bean *in litt*. 2019; H. T. Harvey and Associates *in litt*. 2019; Prowatzke *in litt*. 2019).

We used ESRI ArcGIS Pro for the spatial analyses conducted within this chapter. We cite these data sources for these analyses throughout this section.

Figure 5. The historical range of the giant kangaroo rat. This boundary represents the outer boundary of areas where giant kangaroo rats could have occurred before land-use changes by humans in the 20th century. The predicted, historical range extends over as many as 1.9 million acres on the western slopes of the San Joaquin Valley, California.

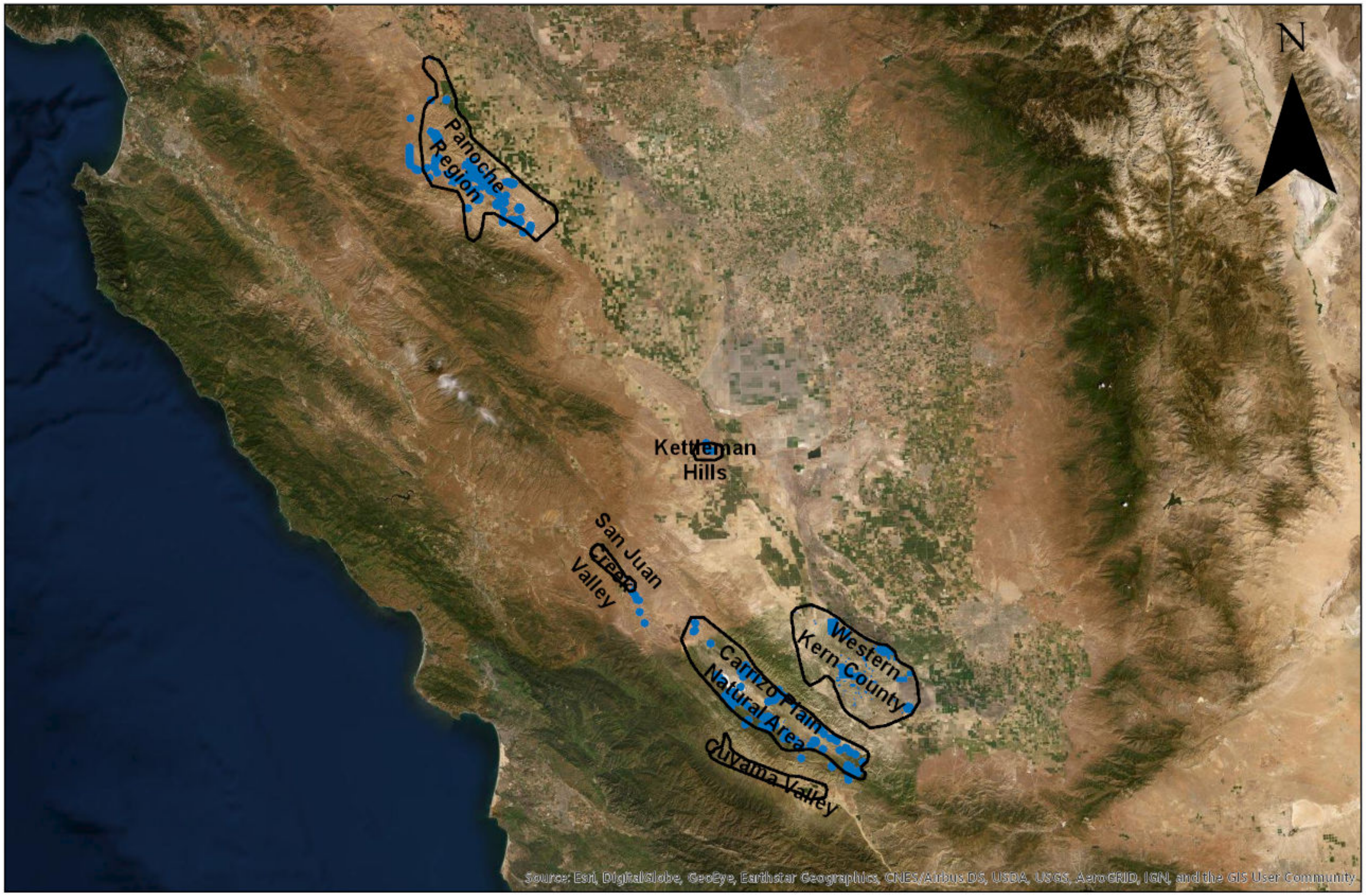
Analysis units

We chose large geographic units to base our analysis of species condition. The units were selected based on the dispersal limits of the species, topographic features, and human land-use changes. While populations might exist outside of these units, they are not consistently occupied or are on private lands that do not have survey data. Throughout the historical range of the giant kangaroo rat, populations exist in six distinct geographic units. Populations within each unit exist in areas of suitable habitat as demographically-distinct populations in discrete regions, which are difficult to identify due to annual population fluctuations.

Today there are six, geographic units where giant kangaroo rats are still known to occur: (1) the Ciervo-Panoche unit in western Fresno and eastern San Benito Counties; (2) Kettleman Hills in southwestern Kings County; (3) San Juan Creek Valley, east of San Luis Obispo County; (4) the Lokern area, Elk Hills (previously Naval Petroleum Reserves Number 1 and 2; NPR-1 and NPR-2), Taft, and Maricopa in western Kern County; (5) the Carrizo Plain in eastern San Luis Obispo County; and (6) the Cuyama Valley along in the east of Santa Barbara-San Luis Obispo County line (Service 1998, p. 87) (Figure 6). The acreage of land within each geographic unit is summarized in Table 4. For a full description of these units, see the recovery plan (Service 1998, p. 87).

Geographic Unit	Acres	Approximate Percent of Historical Range
Ciervo-Panoche	199,870	10.5%
Kettleman Hills	8,942	0.5%
San Juan Creek	14,074	0.7%
Western Kern County	185,553	9.8%
Carrizo Plain Natural Area	184,740	9.7%
Cuyama Valley	37,311	2%

Table 2. Acres of land within the Geographic Units used to analyze the condition of the giant kangaroo rat across the species range. The historical range encompasses approximately 1.9 million acres. However, the analysis units represent a much smaller area currently occupied by the species.



Description: Geographical Units and range-wide occurrence data since the time of listing for the giant kangaroo rat. Data were accessed through the California Natural Diversity Database (CNDDB, 2019) and Humboldt State University (Bean in litt. 2019)

0 12.5 25 50 Miles

GEOGRAPHIC UNITS (ANALYSIS UNITS)
OCCURENCE DATA

Figure 6. The six geographic units used to analyze the condition status of giant kangaroo rats across the species' range. Occurrence data primarily sourced from the California Natural Diversity Database (CNDDB 2019) and academic researchers (Bean *in litt.* 2019).

Historical Range

Historically, giant kangaroo rats existed only in the southwestern plains of the San Joaquin Valley and select valleys of the inner coastal range (Bowers 2004, p. 202; Grinnell 1922, p. 30). Colonies stretched over a large area of continuous habitat within the gently rolling plains on the western slopes of the San Joaquin Valley, Carrizo Plain, and Cuyama Valley (Grinnell 1932, p. 306; Shaw 1934, p. 275; Hawbecker 1944, p. 1944; Hawbecker 1951, p. 161). This area encompasses an estimated area between 1.6 and 1.9 million acres (Figure 5) (Service 1998, p. 85). Currently, there are subpopulations occurring across the northern and southern portions of the species historical range. This divergence appears to have been driven by changing climate conditions after the most recent glacial maximum, resulting in genetic divergence and local adaptations (Statham *et al.* 2019, p. 7).

Current Range

Until the mid-20th century, land within the historical range of the giant kangaroo rat remained mostly in its original configuration (Service 1998, p. 92). Once the state of California completed water infrastructure projects, the land was rapidly cultivated and irrigated along the west side of the San Joaquin Valley (Williams 1992, p. 303). Between the 1950s and 1980s, humans converted vast portions of the San Joaquin Valley from natural ecosystems to crop-land, due primarily to advancements in industrial agricultural practices (Williams *et al.* 1995, p. 1). By the end of the 1980s, nearly all natural ecosystems that provided habitat for the giant kangaroo rat were in agricultural production – reducing habitat for rare species native to the grasslands of the San Joaquin Valley (Service 1998, p. 92).

Currently, less than 5 percent of the original habitat for the giant kangaroo rat remains (CNDDB 2019; Service 2010, p. 3). Subpopulations of giant kangaroo rats are now within six major geographic units (described above), representing two portions of the historical range. These units are themselves fragmented into smaller, demographically independent populations, many of which are isolated by several miles of barriers such as steep terrain or unsuitable habitat, including agriculture and urban development (Service 1998, p. 87).

The healthiest populations of giant kangaroo rats exist at the northern and southern ends of the species' range. These areas represent geographically distant peripheral segments of a once sizeable contiguous range (Statham *et al.* 2019, p. 2). The northern region of the range (Ciervo-Panoche geographic unit) is characterized by small, isolated habitat patches separated by agriculture or steep, sloping hills, which are unlikely to be occupied by the species (Williams *et al.* 1995, pp. 2–6; Alexander 2016, pp. 4–6). Individual giant kangaroo rats within these smaller subpopulations interact somewhat, contributing to gene flow across the northern spatial-unit of the giant kangaroo rat range (Statham *et al.* 2019 p. 2). Not all subpopulations experience the same amount of gene flow across the range. Migration rates between subpopulations are asymmetrical (Statham *et al.* 2019, p. 9). For instance, giant kangaroo rats in Tumey Hills contribute a disproportionate amount of gene flow to other areas within the Ciervo-Panoche geographic unit. In contrast, other populations provide relatively little gene flow to other regions (Statham *et al.* 2019, p. 9).

The southern portion of the historical range contains three geographical units (Table 5). The Carrizo Plain geographical unit harbors the most substantial population which exists on contiguous, protected habitat. Western Kern County harbors another area with some protected land, known as the Lokern lowlands, where populations have fluctuated during cycles of drought and wet years, but have persisted. Less is known about the Cuyama Valley population abundance over time, and the unit contains little protected habitat. The three geographic units which comprise the southern portion of the historical range are distinct from one another. There are topographic features where populations of giant kangaroo rat are not likely to persist, but where gene flow is hypothetically possible between units (Good *et al.* 1997, p. 1308).

It is important to note that there are several genetically distinct populations within the northern portion of the range, especially the Ciervo Hills and Panoche East (Statham *in litt.* 2020). The Panache East population in the San Joaquin Valley has seen substantial range reduction in the last few decades (Statham *et al.* 2019).

There are no genetic data available from the Kettleman Hills and the San Juan Creek units, and it is unclear if these areas are more closely related to the northern or southern portions of the historical range. In the central portion of the species range are two, smaller geographical units (Service 1998, p. 87). Large populations appear to exist in the Kettleman Hills area of northwestern Kern/southwestern Kings County (Bean *et al.* 2019, p. 3). Likewise, there is not much information about populations within the San Juan Creek unit. Aerial surveys show small precincts scattered across the landscape (Bean *et al.* 2019, p. 3). However, this area also has the lowest genetic heterozygosity, suggesting this geographic area has already experienced genetic drift due to small population sizes (Statham *et al.* 2019, p. 3). For this document, and to assess the species' representation, we acknowledge that these two geographic units are probably genetically distinct from the other populations in the northern and southern portions of the range.

Genomic analyses suggest that the northern and southern populations might be under divergent selection pressures (Statham *et al.* 2019, p. 17). Morphological comparisons of giant kangaroo rat populations at the ends of the range suggest that Carrizo Plain individuals are larger than those in the Ciervo-Panoche (Statham *et al.* 2019, p. 17). Northern and southern animals occur in habitats at the opposite ends of the precipitation regime tolerated by the species, which could be driving local adaptation (Statham *et al.* 2019 p. 17).

Of the available habitat patches where giant kangaroo rats still occur, the largest, continuous area of suitable habitat is the Carrizo Plain National Monument ("Carrizo") (Statham *in litt.* 2019). The Carrizo Plain lies at the southern part of the species' range and lies between the Central Valley floor, and the Cuyama Valley (Figure 6) (Widick and Bean 2019, p. 2). Populations within the Carrizo Plain Natural Area appear to be robust, and there has been recent evidence that the local area range has expanded in past years (Axsom *in litt.* 2019). Together, the Carrizo Plain, Cuyama Valley, Lokern ecological preserve on the Central Valley floor comprises the southern portion of the species' range and represents a unique portion of the historical range. Large areas within this southern portion of the range of the giant kangaroo rat have been set aside on federal and state lands along with private easements for the preservation of the species (Table 6; Figure 7).

Habitat for three of the six regional populations of giant kangaroo rats does not include substantial public or conservation lands (Service 1998, p. 93). These areas include the Cuyama Valley, Kettleman Hills, and San Juan Creek Valley. All are small and vulnerable to destruction from demographic and random catastrophic events, and inappropriate land uses.

Portion of Historical Range	Geographic Unit
Northern	Ciervo-Panoche
Middle	San Juan Creek
	Kettleman Hills
Southern	Western Kern County
	Carrizo Plain Natural Area
	Cuyama Valley

Table 3. Categorization of the portions of the historical range and geographic units (analysis units). There are no genetic data from Kettleman Hills and the San Juan Creek units, and it is unclear if these areas are more closely related to the northern or southern portions of the historical range. For this document, we acknowledge this uncertainty by placing them within their own "middle" portion of the historical range.

Geographic Unit	**Percent of Protected Land Within Unit**
Ciervo-Panoche	40.7%
Kettleman Hills	0.0%
San Juan Creek	0.0%
Western Kern County	19.2%
Carrizo Plain Natural Area	76.8%
Cuyama	24.5%

Table 4. Percent of land within each geographic units that is protected by federal or state agencies, which include conservation easements on private properties. Some public areas are managed explicitly for endangered species, while others do not have management assurances in place.

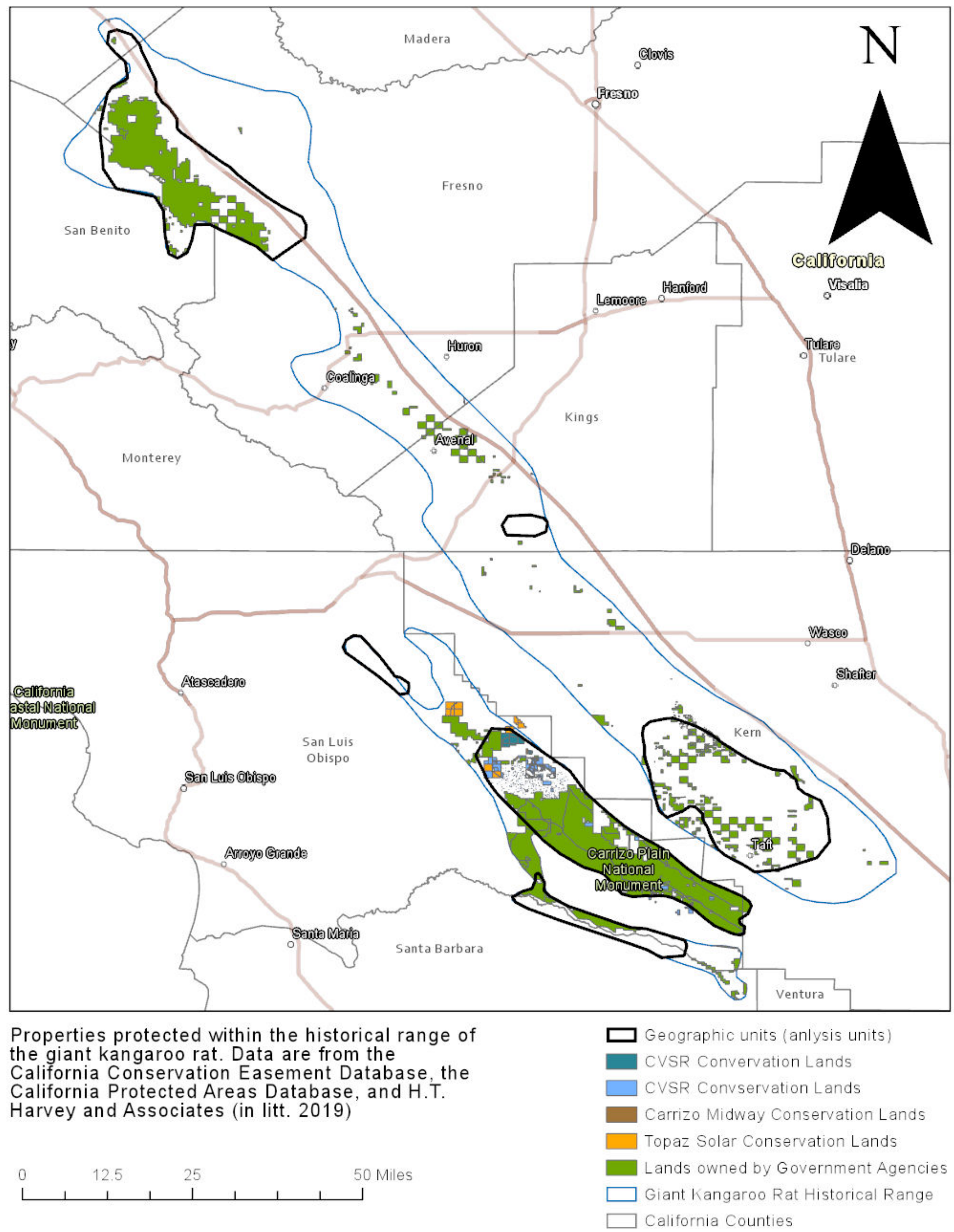


Figure 7. Protected lands throughout the historical range of the giant kangaroo rat. Within some geographic units, such as the Carrizo Plain Natural Area (National Monument), much of the land has been protected by federal and state land management agencies with conservation measures to preserve giant kangaroo rats. Other units have no such protections in place, or the protections within the geographic unit are patchy and discontinuous. Areas without protections allow for continued land-use changes and anthropogenic development, meaning the long-term viability of the giant kangaroo rat in these units is uncertain.

Regulatory Mechanisms and Management Actions

State Laws

California Endangered Species Act (CESA):
The CESA (California Fish and Game Code, section 2080 et seq.) prohibits the unauthorized take of State-listed threatened or endangered species. The CESA requires State agencies to consult with the California Department of Fish and Wildlife that might affect a State-listed species and mitigate any adverse impacts to the species or its habitat. According to CESA, it is unlawful to import or export, take, possess, purchase or sell any species or part or product of any species listed as endangered or threatened. The State may authorize permits for scientific, educational, or management purposes, and to allow take that is incidental to otherwise lawful activities.

California Environmental Quality Act (CEQA):
The CEQA (Chapter 2, section 21050 et seq. of the California Public Resources Code) requires a review of any project undertaken, funded or permitted by the State, a local government agency. If there are significant environmental effects identified, the lead agency has the option of requiring mitigation through changes in the project or to decide that overriding consideration make mitigation infeasible (CEQA Sec. 21002). In the latter case, approval of these projects might cause significant environmental damage, such as destruction of listed endangered species or their habitat. Protection of listed species through CEQA is dependent upon the discretion of the lead agency involved.

Natural Community Conservation Planning Act:
The Natural Community Conservation Program is a cooperative effort to protect local habitats and species. The program helps identify and provide area-wide protection of plants, animals, and their habitats while allowing the compatible and appropriate economic activity. Many Natural Community Conservation Plans (NCCPs) are developed in conjunction with Habitat Conservation Plans (HCPs; see below) prepared according to the Federal Endangered Species Act.

Federal Laws and Regulations

National Environmental Policy Act (NEPA):
NEPA (42 U.S. C. 4371 et seq.) provides some protection for listed species that may be affected by activities undertaken or funded by Federal agencies. Before implementing such projects with a Federal nexus, NEPA requires the agency to analyze the project for potential impacts on the human environment, including natural resources. In cases where that analysis reveals significant environmental effects, the Federal agency must propose mitigation alternatives that would offset those effects (40 CFR 1502.16). These mitigations usually provide some protection for listed species. However, NEPA only requires an impact assessment and that the analysis will become publicly available; full mitigation is not required.

Clean Water Act:
Under section 404, the U.S. Army Corps of Engineers (Corps or USACE) regulates the discharge of fill material into the waters of the United States, which include navigable and isolated waters, headwaters, and adjacent wetlands (33 U.S.C 1344). In general, the term "wetland" refers to areas meeting the Corps' criteria of hydric soils, hydrology (either sufficient annual flooding or water on the soil surface), and hydrophytic vegetation (plants adapted explicitly for growing in wetlands). The Clean Water Act requires a review of any actions with the potential to impact waters of the United States. Such actions will also undergo a review of the National Environmental Policy Act, and

Endangered Species Act. These reviews require consideration of impacts to listed species and their habitats, and recommendations for mitigation of the significant effects. The giant kangaroo rat is an upland species typically found in landscapes with limited jurisdictional waters under the Clean Water Act.

Endangered Species Act (Act):
The Endangered Species Act of 1973, as amended (Act), is the primary Federal law protecting the giant kangaroo rat. The Service has responsibility for administering the Act, including sections 7, 9, and 10 that address the take of endangered species. Section 9 prohibits the taking of any federally listed endangered or threatened species. Take is defined in Section 3 as to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture or collect, or to attempt to engage in any such conduct. Service regulations at 50 CFR 17.3 define harass as an intentional or negligent act or omission, which creates the likelihood of injury to wildlife. If activities annoy an animal to such an extent as to significantly disrupt standard behavior patterns, including, but are not limited to, breeding, feeding, or sheltering. The same regulations define harm as an act that kills or injures wildlife. Harm is further defined to include significant habitat modification or degradation that results in death or injury to listed species by significantly impairing essential behavior patterns, including breeding, feeding, or sheltering. The Act provides for civil and criminal penalties for the unlawful taking of listed species.

Since listing, the Service has analyzed the potential effects of Federal projects under section 7(a)(2), which requires Federal agencies to consult with the Service before authorizing, funding, or carrying out activities that may affect listed species. For projects without a Federal nexus that would likely result in incidental take of listed species, the Service may issue incidental take permits to non-Federal applicants according to section 10(a)(1)(B). We define incidental take as taking that is incidental to, and not the purpose of, the carrying out of an otherwise lawful activity (50 CFR 402.02). To qualify for an incidental take permit, applicants must develop, fund, and implement a Service-approved Habitat Conservation Plan. It details measures to minimize and mitigate the project's adverse impacts to listed species. Many Habitat Conservation Plans work in coordination with the State of California's related Natural Community Conservation Planning program.

As an endangered species under the Act, protections for the giant kangaroo rat can reduce the severity of the effects of habitat degradation and destruction caused by anthropogenic sources, such as agriculture, urban development, and solar power generation (see Section: Habitat Modification and Destruction, below). Development projects that are subject to section 7 consultation or result in the issuance of an incidental take permit under section 10 might include habitat compensation, which can reduce the severity of overall habitat loss typically associated with these projects. Habitat compensation can occur via a variety of mechanisms, including the purchase of credits at approved conservation banks, through permittee responsible mitigation, and through the development of habitat conservation plans (HCPs). Also, section 10(a)(1)(A) of the Act allows permits to be issued for recovery activities that result in take. Recovery activities are implemented explicitly for scientific purposes or enhance the propagation or survival of the affected species, including interstate commerce activities.

Conservation Banks: A mitigation bank or conservation bank (bank) is a property or suite of properties (i.e., umbrella bank, phased bank, etc.), providing habitat or other conservation values that are conserved and managed in perpetuity, and provides ecological functions and services for specified listed species or resources. Mitigation and conservation banks function to offset adverse impacts that occurred elsewhere; therefore, the Service approves a specified number of credits that the bank owner may sell to developers or other project proponents for use as compensation to offset adverse impacts their projects will likely have on listed species. The money from the initial investment and bank credit sales is then used to permanently protect and manage the land for those species and resources. More information about conservation banks within the Sacramento Fish and Wildlife Office's Service area can be found at: https://www.fws.gov/sacramento/es/Conservation-Banking/Banks/In-Area/.

There are currently no active conservation banks for the giant kangaroo rat. The Service is currently considering several areas with active giant kangaroo rat populations for the establishment of conservation banks for the species.

Permittee responsible Mitigation: Permittee-responsible mitigation, also sometimes referred to as turn-key mitigation, includes activities or projects undertaken by a permittee (or authorized agent) to provide compensatory mitigation to offset impacts from a single project. The permittee retains full responsibility for this mitigation. Ideally, permittee-responsible mitigation projects are established in advance of the project-related impacts they are offsetting; however, this typically does not occur due to multiple factors. Habitat compensation through permittee responsible mitigation for the giant kangaroo rat occurs throughout the species range for several projects. The primary agencies implementing permittee responsible mitigation for the giant kangaroo rat include the Bureau of Reclamation, Bureau of Land Management, California Department of Transportation, oil and gas companies, and several solar facilities.

Habitat Conservation Plans: Habitat Conservation Plans (HCPs) are planning documents required as part of an application for an incidental take permit. They describe the anticipated effects of the proposed taking; how those impacts will be minimized, or mitigated; and how the HCP is to be funded. HCPs can apply to both listed and non-listed species, including those that are candidates or have been proposed for listing. Regional HCPs develop large-scale conservation strategies within a specific region that are designed to conserve functional ecological systems and the covered species that depend on them. Such HCPs aim to avoid a fragmented conservation landscape by working with local land use authorities and a designated implementing entity to conserve, enhance, and manage a preserve system. Project-level HCPs are designed to fully offset the impacts associated with the permitted activity by contributing to a larger conservation design.

Being included as a covered species under an HCP can result in habitat being set aside and managed for the species as mitigation for impacts associated with covered activities, such as planned urban development, within the HCP permit area. In addition to mitigation, avoidance, minimization, and other conservation measures (e.g. monitoring, seasonal work windows, habitat management, etc.) are implemented. HCPs can also utilize banks, in-lieu fee programs, or other mechanisms to preserve habitat in perpetuity and contribute to a regional conservation strategy.

There are nine HCPs which include the giant kangaroo rat as a covered species. Table 7 provides a summary of those HCPs and the year the permit for the HCP was issued. More information about HCPs that include the giant kangaroo rat as a covered species can be found at: https://ecos.fws.gov/ecp0/profile/speciesProfile?sId=6051.

Habitat Conservation Plan	Year the Permit was Issued
Seneca and Enron Oil and Gas	1998
PG&E San Joaquin Valley Operations & Maintenance HCP	2007
Nuevo-Torch	1999
Metropolitan Bakersfield	1994
Kern Water Bank	1997
Kern County Waste Facilities	1997
EnviroCycle, Inc.	1993
Chevron Pipeline	1996
ARCO Coles Levee (ARCO Western Energy)	1996

Table 5. Habitat conservation plans which include the giant kangaroo rat as a permitted species.

Recovery Permits: Recovery permits, also referred to as 10(a)(1)(A) permits, allow scientists to take listed species as a means to contribute to the recovery of the listed species. The data acquired from some actions under recovery permits (e.g., occurrence, abundance, distribution, etc.) allow the Service to make informed decisions for the species that will enhance their survival and recovery. The Service issues Recovery permits for activities that directly aid the recovery of a species, such as captive breeding, reintroductions, habitat restoration, removal or reduction of threats, and educational programs. The Service's recovery permitting program aids in the conservation of listed species by ensuring permittees have adequate field experience and qualifications for conducting activities with the target listed species and, for most species, provides that permittees are following standardized protocols while surveying. The recovery permit application process ensures that scientific proposals contain the recommended actions laid out in the Recovery Plan for the target species. There is currently no protocol survey guidance for the giant kangaroo rat; however, there are minimum qualifications to obtain a recovery permit for the subspecies. Minimum qualifications and species-specific protocols are at: https://www.fws.gov/sacramento/es/Permits/

Several long-term monitoring efforts for the giant kangaroo rat are permitted through section 10(a)(1)(A). Through these projects, scientists can better understand how the species responds to climatic fluctuations and changes in land management. Population trend data collected from long term monitoring projects are instrumental for understanding if current, Service-approved management plans are effective. Several small giant kangaroo rat population expansions were reported to the Service through recovery permit reporting; in 2019, there was a range expansion of giant kangaroo rats in the northern portion of the Carrizo Plain (Axsom *in litt.* 2019).

Sikes Act:
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 1997requires Department of Defense installations to prepare Integrated Natural Resource Management Plans (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. The INRMPs incorporate, 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. Currently, there are no known populations of giant kangaroo rats existing on military lands.

Federal Land Policy and Management Act of 1976 (FLPMA):
The Bureau of Land Management is required to incorporate Federal, State, and local input into their management decisions through Federal law. Authorities wrote the FLPMA (Public Law 97-579, 43 USC 1701): "to establish public and land policy; to establish guidelines for its administration; to provide for the management, protection, development, and enhancement of the public lands, and other purposes."

Section 102(f) of the FLPMA states that "the Secretary [of the Interior] shall allow an opportunity for public involvement and by regulation shall establish procedures … to give Federal, State, and local government and the public, adequate notice and opportunity to comment upon and participate in the formulation of plans and programs relating to the management of the public lands." Therefore, through management plans, the Bureau of Land Management is responsible for including input from Federal, State, and local governments and the public. Additionally, Section 102(c) of the FLPMA states that the Secretary shall "give priority to the designation and protection of areas of critical environmental concern" in the development of plans for public lands. The Bureau of Land Management has a multiple-use mandate under the FLPMA, which allows for grazing, mining, and off-road vehicle use. The Bureau of Land Management also has the ability under FLPMA to establish and implement species management areas such as Areas of Critical Environmental Concern, wilderness, research areas, etc., that can reduce or eliminate actions that adversely affect species of concern (including listed species).

The Carrizo Plain National Monument was created by the BLM in 2001 to protect species native to California's central valley, including the giant kangaroo rat. Over two-hundred thousand acres of public land is conserved for the benefit to the public.

National Wildlife Refuge System Improvement Act of 1997:
This act establishes the protection of biodiversity as the primary purpose of the National Wildlife Refuge system. This has led to various management actions to benefit federally listed species. The giant kangaroo rat does not exist on any established national wildlife refuge lands.

Stressors Affecting the Species' Condition and Related Conservation Measures

In this section, we discuss how the long-term viability of the giant kangaroo rat is affected by the 3Rs (Figure 8). Here, we consider the external factors (stressors) that might influence the 3Rs, and thus the viability of the giant kangaroo rat (Figure 9). Previous documents that address the status of the species (Service 1987, entire; Service 1998, entire; Service 2010, entire) describe some of these influences as threats. Here, we will use the term 'stressor' to include previously identified threats and other factors that might affect the overall viability of the species.

Through studying the available literature, we chose to evaluate stressors for which there is a broad consensus of the potential to impact the species. Examples of these stressors include habitat modification and destruction, drought, flooding, disease or pathogens, rodenticides, wildfire, over-grazing, inbreeding, and genetic drift. There are other possible stressors impacting the survival of the giant kangaroo rat identified in other documents on the species (i.e., off-road vehicle use, predation) (Service 2010, p. 36); however, they do not have a broad consensus of the potential to impact the species. Therefore, some stressors we intentionally omitted from the analysis of this SSA. For the stressors we did include, we describe the magnitude of the stressor, an influence diagram modeling the potential impacts of the stressor on population resiliency, and a summary of ongoing and prospective conservation that might reduce these impacts.

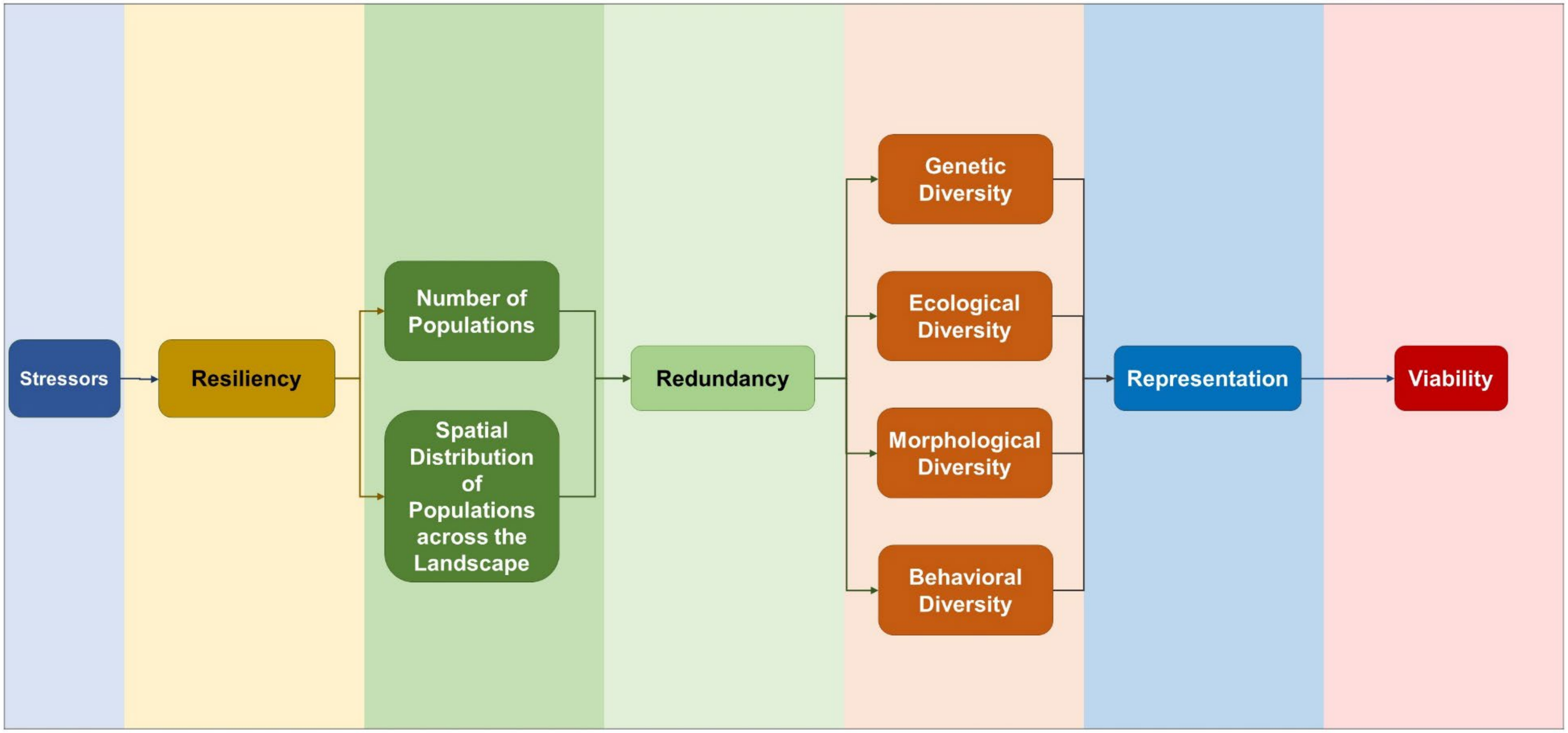


Figure 8. General influence diagram modeling how stressors can impact the viability of the giant kangaroo rat. Stressors act on the ability of a population to respond to environmental change (resiliency). The number and spatial distribution of populations across the species' range characterize its redundancy. Any differences in the genetic, ecological, morphological, or behavioral features of these populations influence the species representation. Together, the 3Rs describe the overall ability of the species to maintain populations in the wild into the foreseeable future. That is, the 3Rs impact the species viability.

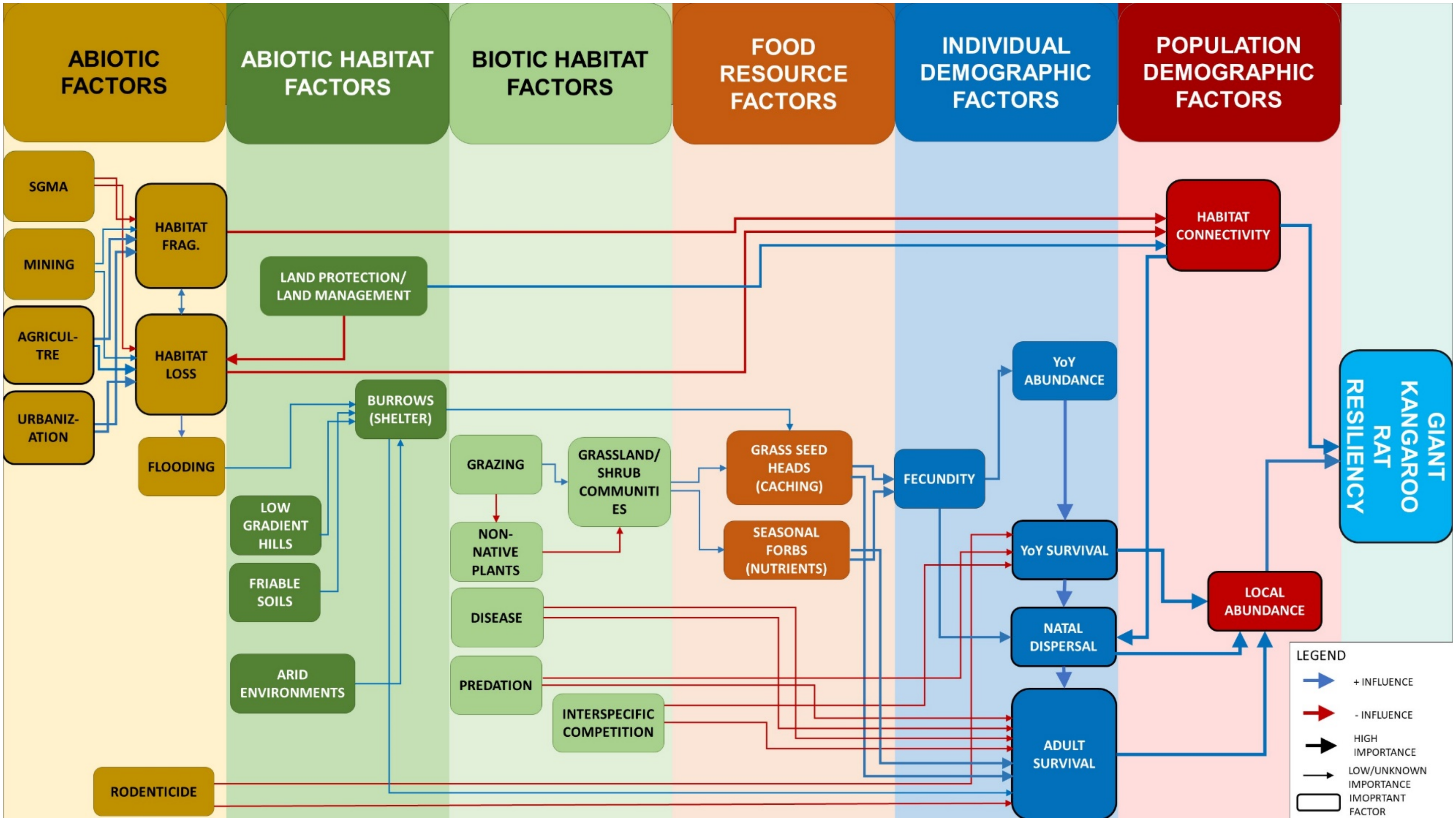


Figure 9. Influence diagram modeling how various factors influence population resiliency of the giant kangaroo rat.

Experts believe habitat loss and fragmentation are the main stressors that negatively impact the resiliency of giant kangaroo rat populations (Service 1998, p. ix; Service 2010, pp. 19–27). However, there is still uncertainty associated with the future of giant kangaroo rat conservation. For example, the Sustainable Groundwater Management Act (SGMA) could have a positive impact on the species, as agricultural fields might become fallowed. Retired farm fields have the potential to be restored to natural conditions (Kelsey *et al.* 2019 pers. comm.). Strategic land retirement and restoration might allow for species to recolonize previously occupied habitat, reducing habitat fragmentation, and increasing gene flow across the environment (Kelsey *et al.* 2019 pers. comm.). However, the future of this program is uncertain. Currently, agricultural conversion continues within the Joaquin Valley, removing more lands from natural habitat (San Joaquin Valley Upland Species SSA: Expert elicitation meeting 2019).

Habitat Modification or Destruction

The giant kangaroo rat historically existed on low, sloping grassland habitat in the western margins of the San Joaquin Desert, which today is mostly in agricultural use, leaving remaining habitat fragmented (Williams 1992, p. 303). The giant kangaroo rat now exists in a restricted portion of its historical range (Blackhawk *et al.* 2017, p. 261). In general, habitat loss is the primary cause of endangerment to flora and fauna in the San Joaquin Valley (Service 1998, p. ix).

As habitat loss increases, so does habitat fragmentation, leading to a decrease in habitat patch size and an increase in non-habitat, or matrix habitat, between patches. Both the loss of habitat and the rise of isolation of habitat patches can reduce populations to such low levels that local extirpation is likely (Figure 10) (Gaines *et al.* 1997, p. 294). The 1998 recovery plan estimated that less than 5 percent (approximately 150 thousand acres or 60,700 hectares) of habitat on the San Joaquin Valley floor remained in native habitat (Service 1998, p. 1). Today, at least 59% of habitat in the San Joaquin Valley has been converted to agriculture and or urban areas (Germano *et al.* 2011, pp. 140–145). At the time of listing, the Service identified land conversion to agriculture as the primary stressor leading to the decline of the giant kangaroo rat (Service 1987, p. 283).

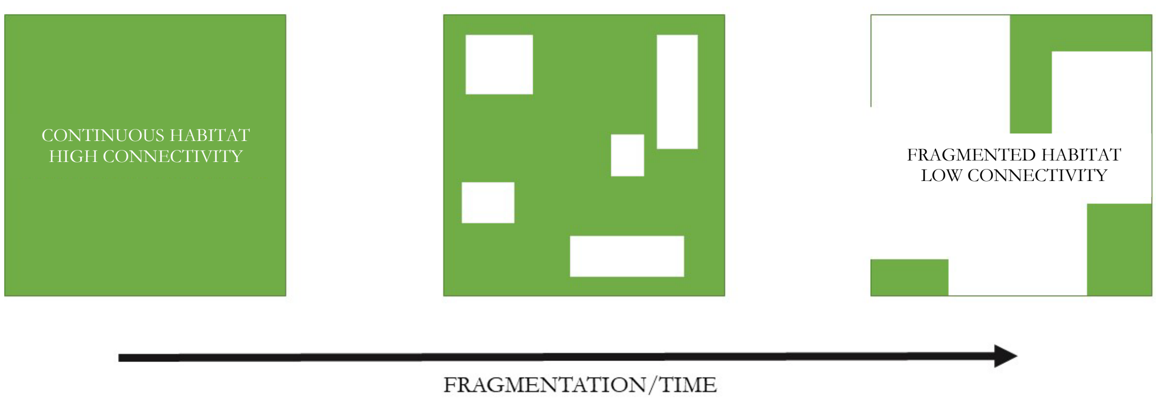


Figure 10. Habitat fragmentation model. This model shows the inverse relationship between increasing fragmentation and decreasing habitat connectivity in the San Joaquin Valley. Over time, as Europeans settled the valley and began farming, habitat fragmentation increased, as habitat connectivity decreased, eventually leading to the highly fragmented habitat patchwork within a matrix of non-habitat we see today.

Due to transportation infrastructure, energy development, agriculture, and urbanization, land conversion continues to stress the giant kangaroo rat and its habitat while also presenting an obstacle to recovery efforts. However, conservation practices and land acquisitions since the time of listing have increased the amount of protected land, and the species' has expanded to nearly 5 percent of its historical range (Service 2010, p. 19). Still, small remnant habitat patches, primarily on private land, continue to be altered for agricultural use. Although conservation efforts have helped the species in recent years, habitat loss, in general, remains the most significant factor which negatively affects the viability of the giant kangaroo rat (Service 2010, p. 19).

Agriculture

At the time of listing, conversion of habitat to agriculture was the primary stressor causing the decline of the giant kangaroo rat (Service 1987). Surveys do not find giant kangaroo rat populations on cultivated lands, and experts believe that agriculture destroys local communities and presents a barrier to dispersal for giant kangaroo rats (Williams 1992, p. 313). Presently, most land suitable for agriculture is already in production. Thus, native habitat conversion has slowed substantially. The areas that remain in a natural state are mostly too rugged to be converted to agriculture (B. Cypher, Endangered Species Recovery Team, *in litt.* 2009). The previous 5-year review did not consider land-use conversion to be a current stressor to the species (Service 2010, p. 19).

However, small isolated patches of giant kangaroo rat habitat on private land continue to be placed into agriculture, but the rate at which this conversion is happening is unclear. Also, large swaths of land converted to agriculture in the previous century remain unsuitable for the giant kangaroo rat and present barriers to dispersal. Because agricultural conversion of lands has not completely halted, and properties previously converted to agriculture increase habitat fragmentation and reduce connectivity, current agricultural processes still reduce species resiliency across the range. In general, habitat conversion to agriculture does not require additional permits in areas zoned for agriculture (Cates *in litt.* 2017). Although agricultural conversion rates might have slowed, habitat loss and fragmentation to agricultural practices still present a challenges to recovery efforts and conversation of the species.

Urban and Residential Development

Some areas of giant kangaroo rat habitat, particularly on the floor of the San Joaquin Valley, are impacted by urban and residential development (Service 2010, p. 24). In areas where progress has already removed habitat, giant kangaroo rats are rarely ever found again, suggesting they do not survive in urbanized areas (Service 2010, p. 24).

Habitat modification and destruction via residential or commercial development will continue in the future. As the human population in the San Joaquin Valley increases, housing/commercial development continue to threaten giant kangaroo rat habitat, albeit at a reduced rate compared to the threat posed by other construction types. Projections show the total number of households in the San Joaquin Valley will increase by just over 1 percent per year from 2010 to 2050, with the highest annual growth rates in Merced and Madera Counties (The Planning Center 2012, pp. 13–14). By 2050, over 6.5 million people are likely to live in the San Joaquin Valley, an increase from 4 million in 2010 (The Planning Center 2012, pp. 17–18).

There have been some Habitat Conservation Plans (HCPs) issued to help reduce the effect of urban development into native habitat and it is possible additional HCPs may be developed in the future as urbanization continues on the valley floor (Service 2010, p. 24-25). However, if there are no conservation assurances in place, urbanization will continue to affect giant kangaroo rats negatively.

Solar Power Development

There have been several proposals for solar projects on lands within the range of the giant kangaroo rat (Service 2010, pp. 20–22). We do not know of any studies which address the potential effect of solar plants on the presence of giant kangaroo rats; however, these projects could negatively impact the species. Solar installations may alter landscape topography, vegetation communities, and soil drainage (Service 2010, pp. 20–21). The construction of large-scale transmission lines associated with solar power generation can destroy or fragment giant kangaroo rat habitat if they pass through natural lands. Additional impacts could occur from regular maintenance activities for solar panels and transmission lines, which would require the construction of roads and right-of-ways, further negatively impacting habitat. (Service 2010, p. 21).

There have been three solar installations completed within the range of the giant kangaroo rat; the Topaz Solar Farms Project (Topaz Solar), the California Valley Solar Ranch (CVSR) and the Panoche Valley Solar Farm (H. T. Harvey & Associates 2015; H. T. Harvey & Associates 2017; Axsom *in litt.* 2019; Bean *in litt.* 2020). These facilities have set aside areas of natural habitat to offset the effects of habitat loss for solar production totaling over 14,000 acres of protected habitat within the Carrizo plain (Axsom *in litt.* 2019; Figure 11). These properties consist of mainly low, rolling hills with some flat areas; most of the vegetation is annual grassland dominated by invasive grasses (Axsom *in litt.* 2019). Habitat in these areas is considered sub-optimal habitat for giant kangaroo rats. However, in 2016 giant kangaroo rat sign was first noted by biologists in the field, and by 2018 populations were confirmed on conservation lands (Axsom *in litt.* 2019). These data could be evidence of a range expansion into an area previously unoccupied by giant kangaroo rats for many years.

Oil and Gas Extraction

Oil and gas exploration and development continue to degrade giant kangaroo rat habitat in western Kern, Kings, and Fresno Counties. Studies show that giant kangaroo rat burrows occur most frequently, and in the highest densities, on the valley floors in areas which are not underlain by extensive petroleum where the potential for negative impacts are low (O'Farrell *et al.* 2016, p. 12; O'Farrell *et al.* 1987, entire). In fact, over four years, only eight burrows were found near proposed construction surveys in oil and gas fields, and no proposed projects had to be modified to avoid effects to the species (Kato *et al.* 1985, entire).

The BLM California has proposed expanding oil and gas development on federal lands in California within the San Joaquin Valley (Bureau of Land Management 2019, online access). If approved, activities could include hydraulic fracturing and other enhanced extraction techniques (Bureau of Land Management 2019, online access). Previously, there have been extraction activities in the Ciervo-Panoche Natural area, as well as Elk Hills-Lokern sites owned and operated by the BLM, where giant kangaroo rat colonies continue to persist (Service 2010, p. 23). Construction of facilities related to oil and natural gas production and associated service roads can fragment and degrade habitat through the development of service roads and other infrastructure around well pads (Service 2010, p. 22). Within areas of oil and gas extraction, observers have detected giant kangaroo rats close to dirt access roads, although they do not appear to do so frequently (O'Farrell *et al.* 2016, p. 2). Infrastructure from oil and gas fragment habitat, rendering land unsuitable or marginal for the species.

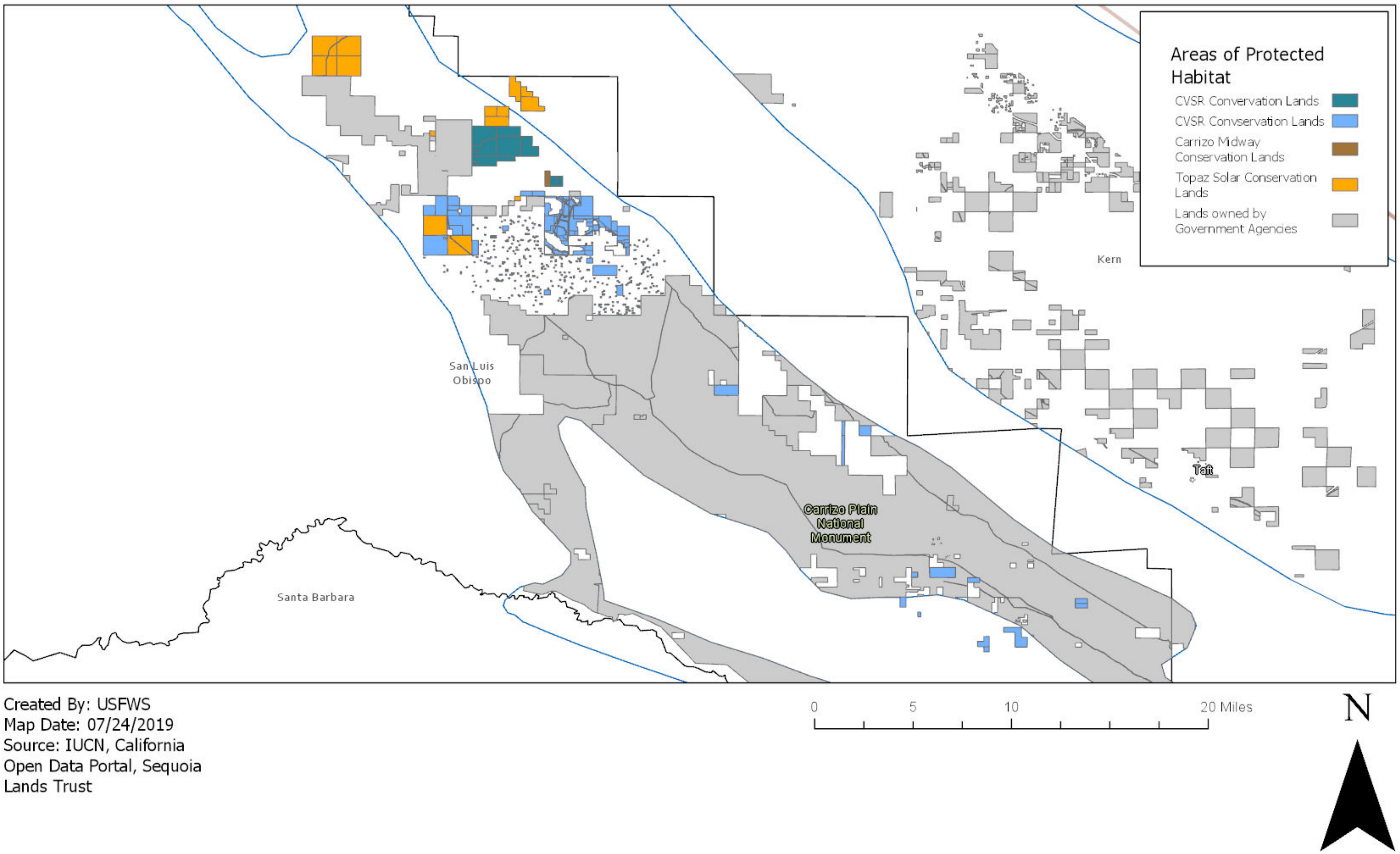


Figure 11. Conservation areas set aside for large solar projects, Topaz Solar and CVSR, in the Carrizo Plain. In recent years, giant kangaroo rats have expanded onto these large areas of continuous habitat.

Permanent modification to habitat due to oil and gas activities can reduce the species' ability to disperse and find new habitat. As more land is effected by the extraction of natural resources, there could be population-level responses associated with habitat degradation and habitat modification. We do not fully understand the effects of current or future mining and extraction efforts on the giant kangaroo rat.

Transportation Infrastructure

Road construction and maintenance can destroy giant kangaroo rat habitat, fragment existing habitat, and alter vegetation while increasing the likelihood of mortality from vehicle strikes (Service 2010, p. 25). The expansion of highways within the species' range has permanently removed large areas of habitat, and temporarily disturbed additional habitat, creating long-lasting population-level effects to the species (Service 2010, p. 25). However, the California Department of Transportation often offsets these effects to the giant kangaroo rat by purchasing and protecting the habitat outside of the highway project footprint (Service 2010, p. 25).

Habitat Modification Summary of Impacts to the 3Rs

Reduction in habitat quality and quantity due to human-induced land-use change can alter the local habitat composition of an area making populations of giant kangaroo rat less resilient and more vulnerable to stochastic events. Habitat fragmentation can also reduce connectivity and prevent gene flow among precincts, leading to a reduction in population resiliency and species redundancy. In some areas, land protections have been put in place to prevent further alterations to native habitat. Mitigation and restoration have been completed in some regions to restore lands that were once suitable habitat back to their native state. These conservation lands have allowed for populations to expand into areas that have been unoccupied for decades.

While conservation and restoration efforts have had positive effects on the species, habitat loss and fragmentation from permanent land conversion have already impacted the resiliency, redundancy, and representation of the species throughout its range. Habitat fragmentation due to the construction of access roads could also reduce connectivity and limit gene flow across the landscape, leading to a reduction in population resiliency and species redundancy. While conservation efforts have increased since the time of listing, habitat modification and destruction remain a stressor to the long-term viability and the eventual recovery of the giant kangaroo rat.

Climatic Variability

Under current, reasonable climate change scenarios, the San Joaquin Valley is likely to see changes in ecosystem processes as a result of predicted climate change (Nogeire-McRae *et al.* 2019, pp. 2, 4). The giant kangaroo rat lives in an area of California known as a climatic desert, with low annual rainfall. Precipitation typically occurs in the winter months – primarily between October and April (Galloway and Riley 2006, p. 25). Historically there has been inter-annual variation in precipitation and temperature (see above section *Habitat*). These are dynamic processes to which native species have adapted. However, projections show that future climatic processes will be more variable under predicted future climate scenarios, and extreme droughts punctuated by heavy, episodic rainfall are both reasonable climate predictions (Widick and Bean 2019 p. 2). Both drought and heavy rain have caused population declines of giant kangaroo rats in the past (Williams 1995, p. 3-6; Single *et al.* 1996, entire; Bean *et al.* 2018, p. 37).

Increasing variability in inter-annual precipitation is already affecting portions of southern California, including the San Joaquin Valley (Stewart *et al.* 2019, p. 6; Widick and Bean 2019, pp. 2–3). Weather patterns altered from historical norms are likely to affect annual rainfall; variation in annual rainfall can affect food availability for individual giant kangaroo rats, causing population-level responses (Williams 1992; Williams and Germano 1994).

Cycles of Population Fluctuations

Rodents living in arid environments are resource-limited by water availability (Brown and Ernest 2002, pp. 979–980). Populations of desert rodents often fluctuate because they experience boom-and-bust cycles caused by pulses in primary production tied to episodic rainfall (Ostfeld and Keesing 2000, pp. 232–236; Previtali *et al.* 2009, pp. 2003–2004). These occasional, heavy rains are attributed to annual precipitation variation, or less predictable weather events, such as the El Niño Oscillation, and can affect rodent populations (Brown and Ernest 2002, p. 983; Thibault and Brown 2008, pp. 3411–3414) (Figure 12).

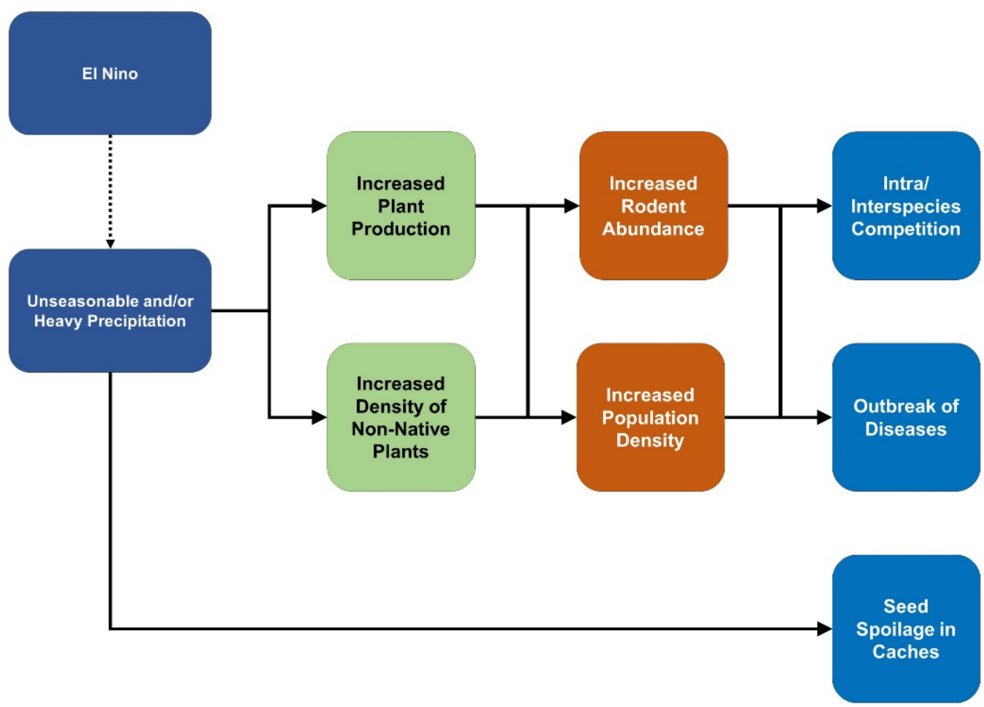


Figure 12. A conceptual model is showing how pulses in resource availability can be transmitted up a food chain to affect higher trophic levels, specifically desert rodent species. El Niño events lead to above-average precipitation, which spurs increased plant production throughout a season. Abundant plant resources can cause an overabundance of rodents in an area, increasing the risk of disease due to increased population density. Additionally, in the SJV, increased precipitation causes non-native grasses to out-compete native plants, causing dense stands of grass to grow, impeding the movement of giant kangaroo rats. In the case of *Dipodomys* species, precipitation can spoilage cached food resources or food-related illnesses and deaths (Brown and Ernest 2002, p. 980).

Many species of kangaroo rats experience cycles of population expansion and contraction (Thilbault and Brown 2007, p. 3411). Such species experience high, inter-annual population fluctuations, the low point of which can be of high conservation concern (Germano and Saslaw 2017, p. 1615). When habitat patches are fragmented or isolated and there is a severe declines in local abundance, local population extinction is more likely because there is little chance of reestablishment (Germano and Saslaw 2017, p. 1615). Giant kangaroo rat populations are also greatly affected by changes in precipitation and herbaceous plant growth (Germano and Saslaw 2017, p. 1616). An extreme drought in California, which lasted approximately from 2013 – 2016, saw precipitous declines in giant kangaroo rat numbers (Prugh 2018, p. 2). Research has shown there is a correlation between episodes of unseasonable, heavy rainfall with reductions of giant kangaroo rats in past years (Single *et al.* 1996, p 36; Germano *et al.* 2001, p. 553). In 2019, a high rainfall year across the range of the species, similar declines were seen in the Carrizo National Monument (Semerdjian *in litt.* 2019). Survival was lower than average in 2018-2019, but primary productivity was not as high as it was during an extreme population decline of giant kangaroo rats in the mid-1990s (Bean *in litt.* 2020). These events show a pattern of population declines following high-rainfall events, which lasted into the summer months.

Drought

As our climate warms, droughts have become more frequent and severe (Trenberth *et al.* 2019, p. 21). Since the beginning of the 20th century, annual average air temperatures have increased in California by about 0.84℃ (1.5°F) (Bales 2013, p. 2; Romero-Lankao *et al.* 2014, pp. 1452–1453). Although drought is a relatively normal process throughout southern California, under climate change scenarios natural, historical stressors (i.e., drought, wildfires, flooding, etc.) have the potential to become exacerbated and extreme, due to anthropogenic factors. The severity of droughts in the western United States has already doubled between 1900 and 2000, a trend which is expected to continue (Cook *et al.* 2004, p. 1016). This has produced a trend of increasing drought severity in recent years (Cook *et al.* 2004, p. 1016).

The most recent severe drought in the San Joaquin Valley lasted for five years from 2012-2017, and was the driest period on record for the region throughout the past 1,200 years (Prugh *et al.* 2018, p. 1). This was widely considered to be the worst drought in history, causing declines in abundance for many flora and fauna of the region (Prugh *et al.* 2018, entire). Giant kangaroo rats are physically and behaviorally adapted to living in an arid environment and thrive during periods of annual aridity. However, prolonged droughts (>2 years) reduce the annual available food supply and cause populations to crash (Germano and Saslaw 2017, p. 1624). Researchers in the Carrizo Plain geographic unit suggested giant kangaroo rats were resistant to one-year water deficits, hypothesizing that large seed caches helped them survive short-term resources shortages (Prugh *et al.* 2018, p. 4). However, once the drought took hold of the region, there was an 11-fold decrease in numbers (Prugh *et al.* 2018 pp. 4–5). In fact, many researchers marked dramatic declines in abundance across the range of the species during the 2012-2017 drought in California (Germano and Saslaw 2017, p. 1624; Prugh *et al.* 2018 p. 2; Bean *et al.* 2014). Therefore, prolonged dry periods place a significant stress on the species viability. Low connectivity, increased fragmentation, and other anthropogenic habitat factors further exacerbate these effects on the landscape.

High Precipitation

Precipitation appears to play a role in limiting giant kangaroo rat distribution (Bean *et al.* 2014, p. 6) However, the specific mechanisms by which precipitation limits the range of the species are not well understood (Bean 2012, p. 2). In general, small mammals in the San Joaquin Valley decline precipitously during especially wet years (Germano *et al.* 2001, p. 553). It has been hypothesized that seasonal flooding can affect giant kangaroo rats negatively in three ways. First, it is possible for burrows to flood, causing direct mortality by drowning (Single *et al.* 1996, p. 38). Observations submitted to iNaturalist suggest there have been direct mortalities due to flooding in 2019, an unseasonably wet year for the San Joaquin Valley (California Academy of Science 2019, retrieved from "inaturalist.org"). Secondly, any precipitation which falls during the normally dry summers can affect seeds caches; moisture can increase the likelihood of mold and other fungi. Experts hypothesize this might cause seeds to spoil harming individual giant kangaroo rats through toxins or spores which when ingested, appear to be lethal (Germano *et al.* 2001, p. 553; Germano and Saslaw 2017, p. 1624). The development of pathogenic toxic molds has been recognized by several observers. (Frank 1988 p. 358; Single *et al.* 1996 p. 40; Germano *et al.* 2001, p. 553). Third, it has been suggested that greater than normal rainfall and associated dense grass growth could make it harder for giant kangaroo rats to move throughout their environment using their distinctive ricochetal movement (Germano *et al.* 2001, p. 559).

Rodenticides

The giant kangaroo rat was once widespread, but populations have decreased since the early 1900s, in part due to non-target exposure to rodenticides when ranchers attempted to eliminate the California ground squirrel (*Spermophilus beecheyi*) on grazing land. From the 1960s into the early 1980s rodenticides were often broadcast over large areas by airplane (Service 1998, p. 92). There continue to be large areas previously treated with rodenticides in western Kings and Kern County and the foothills of Fresno County that once supported giant kangaroo rats but records of giant kangaroo rats have not been reported in many years (Williams 1992; Semerdjian 2019, p. 29).

Today, it is difficult to assess the magnitude of stress rodenticides continue to pose to giant kangaroo rat populations. The state of California no longer broadcasts rodenticides over large areas of habitat (Service 2010, p. 33). However, anticoagulant rodenticides are still used in agriculture to prevent damage to plants by wild rodent species (Franklin *et al.* 2018, p. 1). Anticoagulant rodenticide exposure and poisoning has emerged as a conservation concern for non-target wildlife on public lands (Gabriel *et al.* 2012, p. 1). Many agricultural lands have seen conversion to orchards and vineyards in recent years (U.S Department of Agriculture, 2019, online access). Therefore, we believe anticoagulant rodenticides might be a current stressor to kangaroo rats in areas where habitat is adjacent to agricultural lands, or where private cultivation is carried out on public lands.

Additionally, the number and extent of cannabis farms have increased since the 1990s, and in 2018 the state of California legalized cultivation of the crop (California Department of Fish and Wildlife 2018, p. 2; Franklin *et al.* 2018, p. 1). The past several years have seen an "explosion" of cannabis farms, legal and illegal, develop on the Carrizo Plain geographic unit, where giant kangaroo rats have persisted in high numbers (Vaughan 2017, entire). One of the environmental effects of cannabis cultivation in California is the extensive use of anticoagulant rodenticides to prevent damage to plants caused by wild rodents (Franklin *et al.* 2018, p. 1). Intensive cannabis cultivation causes a potentially significant stressor to giant kangaroo rats, especially populations within the Carrizo Plain geographic unit (Vaughan 2017, entire). Already, reports of dead kangaroo rats have been reported from California Valley, at the northern end of the Carrizo Plain, where cultivation has been more intensive (Vaughan 2017, entire).

Rodenticides Summary of Impacts to the 3Rs

In the latter half of the 20th century, rodenticides played a large role in reducing the overall resiliency, redundancy, and representation across the range of the species, by causing widespread mortality to individuals who were exposed to aerial application of rodenticides. Today, the magnitude of effects to the species from rodenticides is much more difficult to assess, but many individuals are likely still exposed annually. In recent years, legal and illegal cannabis cultivation has probably increased the likelihood of exposure to rodenticides. Local representation and redundancy will be reduced by rodenticides if large numbers of giant kangaroo rats are exposed.

Inbreeding and Genetic Drift

Small isolated populations, such as those on fragmented habitat, are at risk of extinction through random catastrophic or demographic events (Frankham 1998, p. 665). Several populations of giant kangaroo rats, particularly those in the Ciervo-Panoche region of the northern population of giant kangaroo rats are small and fragmented (Service 2010, p. 34). These populations are genetically isolated and at an increased risk of extinction (Good *et al.* 1997, p. 1297; Loew *et al.* 2005, p. 496). Additionally, populations with low genetic diversity are at increased risk that random environmental events such as disease will eliminate them (Loehle and Eschenbach 2012, pp. 87–89).

Genetic analysis shows that populations of giant kangaroo rats have fluctuated over time, and/or that populations have not been isolated from one another for a substantial period of time (Good *et al.* 1997, p. 1306; Loew *et al.* 2005, p. 504–506). The northern lineages maintained some of the oldest alleles (Good *et al.* 1997, p. 1306–1307). One population appeared to contribute more to the genetic maintenance of the entire region (Good *et al.* 1997, p. 1307). The northern populations exhibit nonrandom mating and genetic drift within the metapopulations (Loew *et al.* 2005, p. 506).

Although researchers found low levels of genetic diversity within each population, there was a high degree of genetic diversity among populations (Good *et al.* 1997, p. 3016; Loew *et al.* 2005, p. 503). Recent surveys suggest there is still high genetic diversity among populations in the northern portion of the giant kangaroo rat range (Statham *et al.* 2019, p. 4-6). However, even small changes in population structure due to habitat loss can further affect the population size and dispersal, compromising long-term sustainability of each fragmented population (Blackhawk *et al.* 2016, p. 261). Therefore, loss of any of these small, unique subpopulations will reduce the overall high genetic diversity of the northern range metapopulations (Good *et al.* 1997; Loew *et al.* 2005).

Within the Panoche Valley, Panoche Creek and Silver Creek are important dispersal corridors, which help alleviate the risk to the species due to genetic isolation (Loew *et al.* 2005). However, giant kangaroo rats have a small dispersal distance, and removal of even small areas within this corridor could further isolate individuals across the north geographic unit. These corridors remain unprotected and subject to residential, agricultural or power development. Panoche Valley is an important source of genetic diversity for the species, with the potential for regional expansion of the giant kangaroo rat within the northern geographic unit highlighting the importance of protecting the populations in this valley (Good *et al.* 1997; Loew *et al.* 2005). However, to date the majority of the Panoche Valley is unprotected private lands. Habitat loss in areas that link subpopulations magnify the threats of genetic isolation by reducing the opportunities for immigration between subpopulations.

Within the southern portion of the historical range, there is also evidence of genetic drift (Blackhawk *et al.* 2016, p. 271). Among all of the sampled populations there were significant amounts of inbreeding as well. This is likely to contribute to random fixation and loss of alleles within populations (Blackhawk *et al.* 2016, p. 271). Dramatic population fluctuations experienced by giant kangaroo rats can accelerate genetic drift, decreasing diversity within populations and increasing differentiation among fragmented populations (Blackhawk *et al.* 2016, p. 272).

Inbreeding and Genetic Drift Summary of Impacts to the 3Rs
There are currently high levels of genetic diversity among populations of giant kangaroo rats, contributing to surprisingly high representation across the species range. However, there might only be high genetic diversity because populations have declined in the recent past. If local extinctions continue at the current rate, the existing diversity could be lost within a few years, and representation would be diminished. Already there is evidence of high genetic drift in many of the isolated populations. Small populations are particularly prone to local extinction and genetic drift because populations of giant kangaroo rat fluctuate significantly on an inter-annual basis. Representation and redundancy would be greatly reduced if local populations are lost or succumb to genetic drift and inbreeding.

Invasive Species

Historically, the deserts of the San Joaquin Valley were open saltbush habitat (Germano *et al.* 2011). The plants and animals of the San Joaquin Valley are adapted to arid, open environments, and are therefore ill-equipped to survive in dense-grass stands created by invasive species (Germano, *et al.* 2001, p. 552). In fact, some evidence suggests that giant kangaroo rat abundance increases as grasses and forb cover decreases (Germano *et al.* 2001, p. 553). Native plant communities were drastically altered in the Central Valley once Europeans introduced livestock and non-native plants (Williams 1992, p. 303). Within the past 200 years, native plant communities were largely replaced by highly invasive bromes and filarees as a result of livestock grazing (Williams 1992, p. 303).

The effect of invasive grasses on giant kangaroo rats is complex. Giant kangaroo rats do not appear to show a preference for native plant seeds over invasive grass and forb seeds (Schiffman 1994, p. 525) and can promote the growth of invasive grasses through caching seeds. The animals continuously modify the ground around precincts through burrowing activity. Within the Carrizo Plain, this chronic disturbance of soil and vegetation promotes the establishment of non-native plant species (Schiffman 1994, p. 524). The invasive grass *Hordeum spp.* (a European species) was significantly more likely to grow on precinct mounds and excluded other plant species (Casto *et al.* 2017, p. 8). When allowed to grow unchecked these plants will often exclude native plant species from persisting and cause the plant community to change drastically (Williams 1992, p. 304).

High levels of non-native herbaceous cover have been found to greatly affect all kangaroo rats in the San Joaquin Desert. If not controlled by grazing, areas experiencing several years of above average precipitation could build up enough herbaceous cover to cause local extinctions. If a source population that persists is not able to recolonize areas affected by high plant cover, those areas will likely remain extirpated (Germano *in litt.* 2020).

The caching behavior of giant kangaroo rats undoubtedly contributes to which plant species germinate near, on, and around precincts (Schiffman 1994, p. 534). Caching has been shown to increase plant diversity of both native and non-native plants where giant kangaroo rats occur (Prugh and Brashares 2012, p. 675). In some areas where giant kangaroo rat burrows are quite dense, as many as 69 precincts per hectare, the disturbance by giant kangaroo rat burrowing can have a significant impacts on the community composition and density of non-native plant species, increasing the abundance of invasive plants (Schiffman 1994, p. 533). This complex relationship between giant kangaroo rats and invasive plants makes it difficult to manage for native plants without disturbing the mammal's burrows (Schiffman 1994, p. 536).

Invasive species impacts to the 3Rs
Communities of the San Joaquin Valley have already been significantly altered by introduced, non-native plant species (Germano *et al.* 2001, p. 555). Where non-native plants are allowed to grow unchecked, resiliency is reduced as individuals attempt to survive in an altered landscape. Over time, representation would also be reduced, if grasses and forbes are allowed to reach densities where landscapes can no longer support populations within certain parts of the range. Where large tracts of non-native plants become established, the overall fitness of giant kangaroo rats may decline due to limited ability to move through tall, dense stands of grasses.

Wildfire

There have not been any comprehensive studies which describe the effect of fire on giant kangaroo rats or their habitat (Williams 1992, p. 314). Some experts maintain that fires are not a regular part of desert ecosystems (Germano *et al.* 2001, p. 555). Still, it is possible that fire is somewhat beneficial to giant kangaroo rat habitat, although it would have a localized negative effect on individuals and populations (Williams 1992, p. 314). Fires can temporarily remove non-native plant species on the landscape and have been associated with increased abundances of terrestrial invertebrates (Germano *et al.* 2001, p. 555). However, fires might maintain invasive grasslands in habitats in the San Joaquin Valley (Germano *et al.* 2001, p. 555) and this effect can be amplified because persistence of non-native grasses artificially increases the frequency and intensity of fires from historical levels in the San Joaquin Valley ecosystem (Germano *et al.* 2011, p. 671).

Unlike many other areas, little is known about the natural fire regime in the San Joaquin Valley (Service 2010 p. 35). Evidence suggests that native plant species are not fired adapted (Germano *et al.* 2011, p. 671). Changes in fire frequency on the landscape, which began with European colonization, might have increased the frequency of wildfires within the range of the giant kangaroo rat (Williams 1992, p. 303). The Bureau of Land Management has experimented with fire as a conservation tool within the range of the giant kangaroo rat, but controlled burns were not as effective as grazing at controlling non-native species, and giant kangaroo rats, along with other small mammals, were asphyxiated in their burrows (Service 2010, p. 35).

Wildfire Summary of impacts to the 3Rs
While fire is a natural process throughout the range of the giant kangaroo rat, it is possible that anthropogenic factors have increased the timing and intensity of rangeland burns. This could have an impact to individuals or populations, but it is not likely to significantly impact the viability of giant kangaroo rats in the wild.

Grazing

The native plant community within the range of the giant kangaroo rat has changed since Europeans colonized California and introduced livestock which overgrazed native plant communities and exotic species of plants were able to take hold in the plains of the central valley (Williams 1992, p. 303). Grazing occurs throughout the range of the giant kangaroo rat (Service 2010, p. 33). Results of studies which sought to quantify the effects of grazing on giant kangaroo rats have been mixed (Williams 1989; Williams and Germano 1994; Germano *et al.* 2001; Kelly *et al.* 2004). Some studies showed declines of giant kangaroo rats on grazed plots during wet years, but it is possible that the giant kangaroo rats declined due to other stressors (See discussion on flooding and increased precipitation).

Within Elk Hills, prescribed sheep grazing has disturbed much of the habitat occupied by giant kangaroo rats on former Naval Petroleum Reserves 1 and 2; in areas where flocks congregate or bed down, vegetation becomes so trampled, only soil remains (O'Farrell *et al.* 2016, p. 5). Within trampled areas, no colonies of giant kangaroo rat were found, suggesting intense grazing is not compatible with long-term population viability.

On rangelands which are not managed or grazed, giant kangaroo rats appear to decline as well (Williams *et al.* 1993). Dense, non-native grasses are allowed to grow unchecked in un-grazed lands, which inhibits the giant kangaroo rat's ability to forage and escape predators (Germano *et al.* 2001). Non-native grasses also increase soil moisture, which can lead to spoiled cached seeds (Williams and Germano 1994, p. 14; Germano *et al.* 2001, p. 553).

Grazing Summary of Impacts to the 3Rs
While overgrazing can disturb individual giant kangaroo rat precincts, intermediate levels of grazing might improve habitat quality overall. It is not thought that grazing significantly decreased giant kangaroo rat viability. Where giant kangaroo rats already exist, grazing likely has a neutral effect on the species. However, grazing can reduce density of exotic grasses during wet years, which could facilitate dispersal into unoccupied habitat by giant kangaroo rats. This interaction would mean there is a positive effect from grazing to the species, especially in areas where fragmentation and connectivity continue to be an issue.

Historical Condition

Distribution

Historically, giant kangaroo rats were found only in the western slopes of the San Joaquin Valley; the Tulare Basin and in the adjacent Carrizo Basin and Cuyama and Panoche valleys (Williams 1992, p. 307). Up until the mid-20th century, colonies of giant kangaroo rats were spread over hundreds of thousands of acres within this region (Service 1998, p. 85). This historical distribution generally coincided with the distribution of marine sediment-derived soils on the south and west margins of the valley (Williams 1992, p. 307). While the giant kangaroo rat range was probably never ubiquitous across these soils, they were locally abundant and widespread throughout their historical range (Grinnell 1932, p. 305).

Abundance

Historical abundances of giant kangaroo rats are difficult to discern, as there were no range-wide studies done prior to the 1930's, and there are few museum specimens (Williams 1992, p. 307). Early studies of the giant kangaroo rat suggest that their precincts dominated the community to the exclusion of other rodent species; colonies were spaced out over the landscape in patches but where giant kangaroo rats did occur, they did so in high numbers (Grinnell 1932, p. 305). Based on best estimates, giant kangaroo rat populations were always widely scattered across the landscape and locally abundant throughout their range (Grinnell 1932, pp. 306–306; O'Farrell 2016, p. 3). Areas which had the highest abundance of giant kangaroo rats historically are those which still have the largest populations today: Ciervo-Panoche in the North, and the Carrizo Basin, Lokern and Elk Hills and Cuyama Valley's to the South (Williams 1992, p. 307).

Stressors

The magnitude of the stressors affecting the giant kangaroo rat has changed over time. Historical populations of giant kangaroo rat were exposed to periodic droughts, wildfires, annual variation in weather patterns, and occasional flooding. Habitat conversion to agriculture during the latter half of the 20th century caused the initial decline of the species. (Williams 1992, p. 303). Along with agricultural conversion, livestock grazing and invasive plant species were introduced to California in the early 1800s (Germano *et. al.* 2001, pp. 551–552). The magnitude of stress from natural processes (i.e., drought, wildfire, and weather patterns) is exacerbated through the processes of habitat fragmentation and reduced habitat connectivity across the range. We do not have information on rates of historical agricultural land conversion prior to the 1950's, but rates have increased dramatically during the latter half the 20th century. Rodent eradication programs, which included aerial application of rodenticides aimed at destroying ground squirrels, affected local populations of giant kangaroo rat as well (Service 1998, p. 92).

Current Condition

Distribution

Populations have persisted in at least four of the six geographic units throughout the range: Ciervo-Panoche Region, the Lokern and Elk Hills area of western Kern County, and the Carrizo Plain Natural area. Experts have evidence that there are still giant kangaroo rats in the Cuyama Valley, however, there have not been surveys in many years (Bean *in litt.* 2020). Little is known about populations within the San Juan Creek and Kettleman Hills units. These units are in private ownership, and regular studies have not been possible. Recent trapping efforts were able to confirm the presence of giant kangaroo rats in both of these units (Semerdjian 2019, p. 23). Aerial footage and personal observations suggest small, isolated populations have been able to persist in these units (San Joaquin Valley Upland Species SSA: Expert elicitation meeting 2019; Semerdjian 2019, pp. 25–26).

Abundance

Since the most recent status review, populations of the giant kangaroo rat have fluctuated on a semi-annual basis. From 2012 – 2016 California experienced a prolonged drought, during which time populations across the range saw declines in abundance. Populations of giant kangaroo rat on the Carrizo plain decreased dramatically during the drought (Prugh *et al.* 2018, p. 2). Once the drought ended, populations appeared to rebound within the affected regions (Bean *in litt.* 2019). However, in the summer of 2019 researchers across the range documented additional population declines (Semerdjian *in litt.* 2019). The cause of these declines is unknown, but could be due to unseasonably wet weather and a prolonged wet season which lasted well into the normally dry summer months (Semerdjian *in litt.* 2019). Populations of giant kangaroo rat have seen similar population declines in years with high summer precipitation and have rebounded successfully. Because of inter-annual population fluctuations, it is difficult to determine long-term population trends in many places.

Within the area of currently occupied habitat, giant kangaroo rats experience annual population fluctuations. Population fluctuations associated with changing weather patterns have been documented since 1979 and likely are a natural part of the species' life history (Service 1998, p. 87). During high population years there can be 6 to 10 times more individuals than during low population years (Williams and Kilburn 1992, p. 333–334: Williams 1993; Williams *et al.* 1995). Because of population fluctuations, measuring changes in occupied areas through surveys has been a more effective way of assessing long-term population viability rather than population numbers.

Stressors

The current stressors affecting giant kangaroo rats are provided in the section stressors affecting species' condition and related conservation measures, which discusses habitat modification or destruction, climate change, rodenticides, inbreeding and genetic drift, wildfire, invasive plant species, and grazing. We did not carry forward all of these stressors into our current condition analysis. A stressor was not considered in the current condition analysis if the magnitude of the stressor across the giant kangaroo rat range is unknown, a negative effect of the stressor has never actually been quantified, or the stressor does not affect giant kangaroo rats at the species level (Table 8). For a stressor to have a negative effect on giant kangaroo rats, both exposure and response must occur. In some cases, we cannot estimate the level of exposure and/or response currently occurring, so we cannot generate an estimate of associated impacts to giant kangaroo rat populations. In other cases, we can measure exposure, but there is evidence to suggest giant kangaroo rats are relatively resilient to the stressor and do not exhibit a measurable negative response, so there is not likely a negative impact to populations.

We acknowledge that some stressors have localized impacts within some giant kangaroo rat populations, but this SSA seeks to quantify the giant kangaroo rat's viability at the species' level.

Stressor	Effect to Individuals or populations is known	Negative Response has been Quantified	Species or Population Level Response	Stressor Carried Forward in Analysis
Habitat Modification or Destruction	Yes	Yes	Yes	Yes
Stochastic Precipitation Patterns	Yes	Yes	Yes	Yes
Drought	Yes	Yes	Yes	Yes
Invasive Plants	Yes	Yes	Yes	No
Rodenticides	Yes	Yes	Unknown	No
Wildfire	Yes	No	No	No
Inbreeding and Genetic drift	No	No	No	No
Disease and Pathogens	No	No	No	No
Grazing	No	No	No	No

Table 6. Consideration of stressors for inclusion in our current conditions analysis for the giant kangaroo rat. To be carried forward into our analysis, the magnitude of the stressor needs to be known, there needs to be a quantified negative response, and the negative response needs to be at the species' level. The only stressors that meet all these criteria are habitat modification, flooding and drought.

Analysis of Current Condition

In this section, we analyze the current conditions of the geographic units of giant kangaroo rats as a way of assessing the species' viability. The goal of this analysis is to evaluate resilience of individual populations and representation and redundancy of the species as a whole in order to evaluate current range-wide viability. Assessing current condition as part of the SSA analysis is associated with, but independent from, assessing habitat suitability. Habitat suitability analyses use a suite of habitat predictor variables known or hypothesized to be important to the ecology and distribution of the species to create models that assess habitat and classify it according to suitability. Thus, different habitat sites that are modeled as "suitable" may be based on varying combinations of predictor variables. Models can be tested using historical or current occurrence data, but habitat modeled as suitable may or may not actually be occupied by, or accessible to, the species. Therefore, while habitat suitability can be an important component of understanding population resiliency and can inform future conservation efforts, habitat suitability alone may not accurately reflect the current condition of a specific population or of the species as a whole. When assessing population condition in the SSA framework, we identify specific habitat and demographic variables thought to be the main drivers of viability of the species. In doing so, we address the individual and population needs of the species, as well as the main factors influencing viability. We use quantitative or qualitative assessments to classify these categories into high, moderate, and low conditions in a Condition Category Table (CCT), and analyze the overall condition of each analysis unit across all of the categories. Using the same table to assess the current and future condition of our analysis units allows for comparison and projection of how the species is doing now verses in future scenarios (described in Chapter 4 of this document). That being said, we refer to "suitable habitat" when analyzing current and future condition of the populations, using modeled or otherwise projected habitat suitability in relation to current and future habitat factors and threats.

We analyzed the current condition of giant kangaroo rats within the six, geographic units identified in the Recovery Plan, as described above (Service 1998, p. 87). These areas continue to encompass the known extant locations for giant kangaroo rats thought to be necessary for the recovery of the species (Service 1998, p. 87). For a geographic unit to be considered in high condition, it must meet the needs listed in the section G*iant Kangaroo Rat Needs* in Chapter 2. At the individual level, these needs include low slopes, seasonal seed-producing plants, and appropriate habitat for dispersal (Table 3). A complete description of these units can be found in the section *Current Range* in Chapter 3. Initially, we sought to include all species needs in our analysis of current condition. However, after consulting with experts and taking into account the data which was available to us, we identified average slope within the unit, winter precipitation, summer precipitation, connectivity, land protection, population trends, and frequency of occupancy as the most important needs to include in this analysis for the reasons described below.

Because it is not possible to attain range-wide data on seed-producing plants and vegetation, we used annual precipitation as a proxy for plant communities. Distribution models for the species suggest that the amount of rainfall during the driest month of the year was the most accurate predictor of giant kangaroo rat presence; areas which received an average of 0 cm of rain appear more suitable (Bean *et al.* 2014, pp 6). Mean annual temperature also appears to be important as giant kangaroo rats appear in areas with temperatures between 14°C and 16°C (Bean *et al.* 2014, p. 6). Additionally, two of the main stressors affecting giant kangaroo rats range-wide, flooding and drought, are directly related to annual precipitation cycles. Therefore, we considered precipitation variability to be an indicator of giant kangaroo rat habitat.

Average slope was included in our analysis because studies show giant kangaroo rats do not occupy areas of steep terrain (Alexander *et al.* 2019, p. 1540). While it is unclear if high-slope areas might be used periodically for dispersal, it is unlikely that high hills or mountains are used as dispersal corridors for the species, based on their limited dispersal capabilities. Therefore, in our analysis areas of high slope within the geographic units was assumed to be unsuitable for the species dispersal needs.

Giant kangaroo rats need primary productivity of grasses and forbes in the winter months for breeding and caching seeds. Primary productivity is difficult to assess at a landscape scale, and cannot be easily predicted into the future. Because sufficient rain must fall in the winter months for seasonal plants to grow, winter precipitation was included in our assessment as a proxy for primary productivity. Data were extracted from PRISM interpolated weather surfaces (4 km resolution) from October through April over a thirty-year average, from 1980–2010 (Similar to Westphal *et al.* 2016, p. 3). These years were selected to give an average outside of the droughts. We considered including years within the current decade because the recent drought was especially severe. However, we decided not to include those years in our analysis because the most recent drought might still have a lasting effect on the current condition of the species. We chose centroids for each unit as the point from which to extract PRISM data. To assess the current condition in relation to winter precipitation, we used 15 cm as the amount of precipitation needed for high primary productivity growth (Grinnell 1934, p. 320; Williams 1992. p. 302). Consecutive years with less than 15 cm of precipitation were considered as lower categories. Frequency and duration of these periods were taken into account while setting thresholds for our categories (Table 9).

Summer precipitation was analyzed separately from winter precipitation because the effect to the species is dramatically different. While giant kangaroo rats need primary productively in the winter months, they rely on their seed caches to sustain them through summer months. If too much precipitation falls, seed caches begin to spoil, likely causing starvation or poisoning from toxic molds (Valone *et al.* 1995, p. 430). Therefore, dry summers are assessed in our condition category table. We extracted data from PRISM similarly to the winter data. Our thresholds were created using species distribution models for giant kangaroo rats (Bean *et al.* 2014, p. 6).

There is agreement among experts that habitat loss and fragmentation are the main stressors to the giant kangaroo rat (San Joaquin Valley Upland Species SSA: Expert elicitation meeting 2019). We assessed the connectivity across each unit to capture the ability of an individual to move across the landscape. We assumed a maximum dispersal distance for an individual to be no more than 2.5 km, based on the best available genetic data (Alexander *et al.* 2019, p. 1540).

At the species and population level, giant kangaroo rats need space and suitable habitat in order for populations to be viable over time. Land protection is important to ensure the long-term viability of the species. The percentage of land within each unit was assessed to determine how much protected land was available to the species. This analysis is consistent with the down- and delisting criteria outlined in the Recovery plan for the species (Service 1998, p. 186).

The demographic needs of the species are presented in two categories in our analysis of current condition: population trend and frequency of occupancy. Similarly, a proxy for fecundity is included through our use of precipitation in the table, because drought years are associated with low reproductive success. Trapping data and aerial imagery of precincts were used to assess the frequency of occupancy throughout the range of the species (Bean *et al.* 2019). We assumed that positive identification of a precinct shows giant kangaroo rat activity within the past 10 years. If there have been positive trapping surveys within the past 5 years, the unit was assumed to be currently occupied.

The criteria presented in our condition category table (Table 9) were used to determine the overall current condition of each giant kangaroo rat population (Table 10; Figure 13). The habitat and demographic factors included in Table 9 were not weighted equally in this analysis. Specifically, in our literature review and discussions with experts, we determined that habitat connectivity, land protection, and frequency of occupancy were the most important factors affecting resiliency (San Joaquin Valley Upland Species SSA: Expert elicitation meeting 2019). Land protection and habitat connectivity were weighted equally, while frequency of occupancy was considered as important as both of these factors combined.

Relative weights were assigned to each factor to maintain these relationships: 2x for land protection and frequency of occupancy, and 1x for all other categories. Each geographic unit was given a numeric score relative to each category (1 for low condition, 2 for moderate condition, and 3 for high condition), and a population's overall condition score was then calculated as the sum of all the factor scores multiplied by their relative weights. Categories with unknown conditions were conservatively given a score of 1, or low. We then translated the overall condition score into a current condition category of low, moderate, or high (Table 9).

Uncertainty of Current Condition Analysis

As discussed in our analysis of current condition, we had to make many assumptions, both in defining condition categories and in assessing condition relative to these categories. These assumptions were informed by a thorough literature review and discussions with species experts. The SSA framework requires us to assess a species' biological status such that the analyses and information provided in this report could be used for a multitude of decisions and activities carried out under the authority of the Act (Service 2016, p.7). Describing the giant kangaroo rat's biological status, and ultimately its viability, is difficult because of the complex, and sometimes unknown, interactions among the stressors that might impact population resiliency. However, we must complete our analysis using the best available information, while acknowledging any key uncertainties or assumptions along the way.

Precipitation was used as a metric to assess aridity and primary productivity throughout the range of the species. While giant kangaroo rats do not respond directly to changes in precipitation, we assumed that habitat suitability was linked to the abundance of giant kangaroo rats. We assumed winter precipitation is needed in order to facilitate primary productivity of plants and seeds. However, the literature show that when rain falls in the summer months, populations of giant kangaroo rats decline. Habitat suitability models show a trend that low summer precipitation is needed for giant kangaroo rats to persist. However, the exact mechanism for how and why these declines occur is not well understood. There might be better ways of assessing habitat suitability and primary productivity, but assessing these unknowns is beyond the scope of this SSA document.

Population demographics are also hard to asses for the giant kangaroo rat. Abundance fluctuates with changing weather patterns, and huge declines and increases have been seen from one year to the next in many giant kangaroo rat populations. Therefore we assumed many of the typical metrics for assessing population health and resiliency, such as population size, sex ratio, or effective population size were not appropriate for this analysis. We used frequency of occupancy to assess the long-term population trends within each geographic unit instead. While this might not capture the entire picture of giant kangaroo rat viability at each location, it does help us understand which populations have been resilient to stochastic changes in the past, and are best suited to future changes and long term viability.

Other assumptions had to be made about rate of land-use change, fragmentation, and climatic variability. We also assumed how the species would respond to these changes based on the best available science and our understanding of the species biology.

	Habitat Factors					Demographic Factors	
Condition	**Average %Slope Within Unit**	**Winter Precipitation**	**30 Year average Summer Precipitation (May-September)**	**Habitat Connectivity**	**Land Protection**	**Population Trend**	**Frequency Of Occupancy (Persistence)**
High	0-6% Slope	There are no periods of drought (<15 cm precipitation) lasting longer than 2 years within the past 30 years	No precipitation in the driest two months	Populations within the unit are well connected to other populations and there is evidence of dispersal	>80% of natural lands protected within unit	Populations Stable or Increasing	Evidence of persistence over the past 10 years and positive trapping results within the past 5 years
Moderate	6-10% Slope	There are no more than 2 periods of prolonged drought (>5 years) throughout the last 30 years	0 - 1 cm of precipitation during driest quarter	Populations within the unit are isolated from one another by 0-5 km of matrix habitat	Between 50% and 80% of natural lands protected within the unit	Population exhibits a slight decline; at least one period shows significant annual declines, but there has been evidence of recovery	Evidence of activity within the past 10 years but negative trapping results/no available data
Low	>10%	There are more than 2 periods of drought, or severe droughts lasting more than 5 years within the past 30 years	>1 cm of precipitation during the driest quarter	Populations within the unit are isolated by >5 km of matrix habitat	<50% of natural lands protected within the unit	Populations shows consistent, substantial decline	Infrequent detectability/ no evidence of activity

Table 7. Condition category table outlining the criteria for ranking populations as low, moderate, or high condition for specific habitat and demographic factors important for the resiliency of giant kangaroo rat populations. For our analysis average slope, winter precipitation, summer precipitation, habitat connectivity, land protection, population trend, and persistence were considered.

Portion of the Historical Range	Population unit	Average Slope Within Unit	Winter Precipitation	Summer Precipitation	Connectivity	Land Protection	Population Trend	Frequency of Occupancy	Overall
Northern	**Panoche Region**	Low	High	Moderate	Moderate	Low	Moderate	High	**MODERATE**
Middle	**Kettleman Hills**	High	Moderate	High	Low	Low	Unknown	Low	**LOW**
	San Juan Creek Valley	Moderate	High	Moderate	Low	Low	Unknown	Low	**LOW**
Southern	**Cuyama Valley**	Moderate	Moderate	Moderate	Low	Low	Unknown	Low	**LOW**
	Western Kern County	High	Moderate	High	Moderate	Low	Moderate	High	**MODERATE**
	Carrizo Plain Natural Area	High	Moderate	High	High	Moderate	Moderate	High	**HIGH**

Table 8. Current condition table rating for all geographic units. These units were rated using high, moderate, or low condition based on seven habitat and demographic factors: slope, winter precipitation, summer precipitation, connectivity, land protection, population trend, and frequency of occupancy. Condition ratings are based on the categories given in Table 9 (conditions category table). The tree habitat and demographic factors were not weighted equally in our determination of overall current condition, as explained in section analysis of current condition by population.

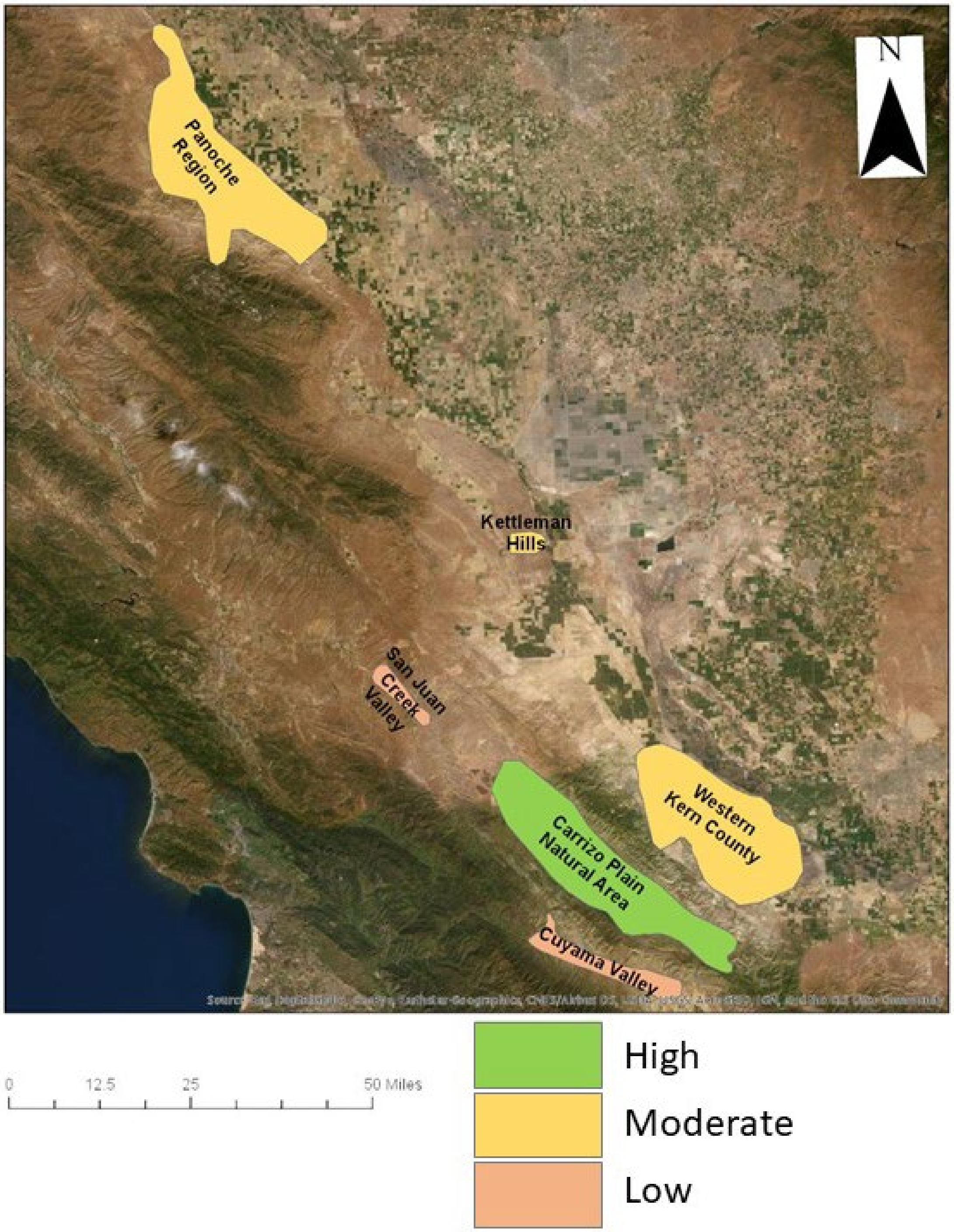


Figure 13. Current condition of geographic units.

CHAPTER 4: FUTURE CONDITION

In this chapter, we predict the future viability of the six giant kangaroo rat population under three, plausible future scenarios. These scenarios use different combinations of climate change impacts, land-use change, and conservation measures to assess overall condition within each unit. This analysis will help predict how viability of the giant kangaroo rat might change in the future and can help guide future conservation efforts.

Factors Influencing Viability

In this section, we discuss factors that might influence giant kangaroo rat viability in the future. All the factors which influence viability discussed previously are still applicable to the future condition of the species. However, they are not expanded on here, unless interactions and species responses are expected to change, which are then discussed in the context of emerging threats, or when trends or models can predict changes to these factors.

Climate Change

There is consensus that increases in greenhouse gas (GHG) emissions during the 20th century have resulted in global climate change characterized by: warming atmospheric and ocean temperatures, diminishing snow and ice, and rising sea levels (Intergovernmental Panel on Climate Change (IPCC) 2014, p. 2-3). Climate change might affect giant kangaroo rats through changes in precipitation and temperature, which can drive associated changes to plant productivity, vegetative communities, and the longevity of seed caches. Climate change is also associated with increased risk of catastrophic events, including floods and wildfires.

Climate models for California under different emission scenarios predict an overall warming effect somewhere between 1.7 and 5.8 degrees Celsius (3.0 to 10.4 degrees Fahrenheit) before 2100 (Cayan *et al.* 2008, p. 7). Giant kangaroo rats are adapted for arid survival and can withstand periods of high temperature. However, the thermal limits of giant kangaroo rat survival have never been tested, and it is unclear how higher average annual temperatures might affect individuals. Studies on banner-tailed kangaroo rats in Arizona found that during daytime summer high temperatures, body temperatures rose within the burrows much higher than expected (Moses *et al.* 2012, pp. 262–263). As air and surface temperatures rise, it is possible that kangaroo rats will no longer be able to escape the heat by burrowing, as ground and soil temperature would rise as well.

Climate change is also associated with changes in precipitation cycles. Extremes in precipitation are expected to increase; current climate models predict a higher frequency of both extremely wet and extremely dry years (Swain *et al.* 2018 p. 427–433). Precipitation extremes are expected to reduce the resiliency of giant kangaroo rat populations, as discussed in *Climatic Variability* above. Giant kangaroo rat abundance decreases after extremely wet years and during prolonged periods of drought (droughts lasting longer than two years) (Swaim *et al.* 2018, pp. 427–433). Extremely wet years can cause over-abundance of dense, non-native grasses, and food spoilage. Stochastic flooding events could also occur, which could negatively affect populations, especially in areas with high slope and topography, such as the Ciervo-Panoche geographic region.

The occurrence of drought years has been higher in the past two decades than in the preceding century, and hot, dry conditions that are correlated with drought are expected to continue (Diffenbaugh *et al.* 2015, pp. 3932–3933). Some future climate projections suggest drought will be more intense; both longer, and dryer than in previous centuries (Trenberth *et al.* 2014, p. 17).

Additional climate change effects are varied. They include those from small, isolated habitat patches, with small populations possibly at higher risk from long-term, intensive droughts (Westphal *et al.* 2016, p. 6); decreases in reproduction and abundance could have irreversible consequences on the population. Within-patch heterogeneity, between patch connectivity, and habitat patch-size, will be important to mitigate population declines from both dry and we years. Changes to climate are also associated with increased risk of wildfires, including both the occurrence of large fires, and the size of burned areas (Westerling *et al.* 2011, p. 457). Large-scale fires have the potential to cause catastrophic declines in giant kangaroo rat populations.

Small population size

Habitat loss and fragmentation are the primary causes of biodiversity loss, including loss of genetic diversity. Small populations can lead to inbreeding depression, which threatens the survival of the species as a whole (Statham *et al.* 2019, p. 2). This is a concern for giant kangaroo rats, because there is little gene flow across the geographic units (Service 1998, p. 92) and populations fluctuate with annual weather cycles (Germano and Saslaw 2019, p. 1624). Still, the genetic diversity for the giant kangaroo rat remains high (Statham *et al.* 2019, p. 2). No one knows exactly how much diversity was lost due to drastic population declines during the 20th century. Low population abundances in small, fragmented habitat patches can lead to inbreeding depression and decreased genetic diversity. These genetic factors often contribute to increased extinction risk (Frankham *et al.* 2014, entire). Small populations have lower fecundity because they have difficulty finding mates. Populations in highly fragmented habitat with small areas of suitable habitat, or that lack connectivity to larger source populations are particularly vulnerable. Populations within the Panoche region, San Juan Creek, and Kettleman Hills units are isolated, patchy, and discontinuous. While the Panoche populations are frequently detected, the genetic structure of the region reveals that metapopulation dynamics may currently be limiting genetic and demographic resilience of these populations (Statham *et al.* 2019, p. 7). This is characteristic of a patchy, discontinuous range.

Habitat Modification and Destruction

Habitat modification and destruction caused by land use changes (e.g. agricultural development, and urbanization) are expected to continue, and most likely to affect habitat on privately held lands. Giant kangaroo rats have never been found on agricultural fields or urban areas, and it is unlikely they will use such modified habitats for any part of their life history (Williams 1992, p. 313).

Agricultural development will be influenced by changes to the climate. Some climate models predict increases in retired croplands in response to increased aridity. Land retirement of agricultural fields across the San Joaquin Valley could result in significant changes to overall land cover; as many as 500,000 acres could be restored to natural habitat by 2040 to meet requirement of existing groundwater regulations (Hanak *et al.* 2017, p. 29). Strategic restoration of retired agricultural land has the potential to aid the recovery of endangered species, including the giant kangaroo rat. The Land Retirement Demonstration Project included a Habitat Restoration Study to investigate the efficacy of restoration techniques on vegetation and wildlife (Uptain *et al.* 2005, pp. 107–175).

Scenarios

For our analysis of the giant kangaroo rat's future condition, we constructed three future scenarios focused on changes in stressors, climate change projections, and levels of conservation efforts (Table 11). While there are an infinite number of potential future scenarios we could have considered, these scenarios are meant to cover a large breadth of future conditions that could occur in the giant kangaroo rat's range. All scenarios might not be equally plausible. To analyze future condition under these scenarios, we projected each scenario 50 years into the future, corresponding to our climate models.

Scenario 1

In scenario 1, we assume there will be warm and wet conditions as described under climate change predictions (CNRM-CM5, RCP 4.5). In this scenario, warm and wet conditions will increase heavy winter rainfall events and summer rains, which will result in increased non-native plant growth, and result in more food spoilage in stored caches. We assume urban and agricultural development will continue at current rates on unprotected lands. There will be limited opportunities for habitat patches to increase in size, or for connectivity to increase or improve throughout the range. We assumed conservation efforts and restoration activities will remain the same as current levels.

Scenario 2

In scenario 2, we assume there will be hot and dry conditions as described under high greenhouse gas concentrations and climate change predictions (MIROC-ESM, RCP 8.5). In this scenario, hot and dry conditions will result in decreases in overall precipitation and an increase in drought intensity and duration. While all future scenarios are impossible to predict with any certainty, current trends show greenhouse gas concentrations are continuing to rise in our atmosphere, consistent with the assumptions of RCP 8.5 (Riahi *et. al.* 2011, pp. 38–51). If trends do not change, this future scenario could be the most likely to occur (Riahi *et. al.* 2011, p. 54). We assume that with hotter and drier conditions there will be an increase in fallowed croplands, without active restoration, within the Central Valley. We assume that development from urbanization will continue at current rates on unprotected lands, with the potential to decrease habitat size and connectivity. Lastly, we assume conservation efforts and restoration activities will remain the same as current levels.

Scenario 3

In scenario 3, we assume there will be hot and dry conditions, similar to scenario 2 (above). We also assume there will be an increase in land protections in the central part of the species range, such that urban and agricultural development will slow and land protections will increase. We assume aggressive habitat restorations will take place on the fallowed croplands throughout the range of the species. Under these assumptions, connectivity and land protections will increase throughout the range.

In all scenarios, we assume increased, stochastic precipitation extremes, meaning droughts, and heavy rainfall events are likely to become more frequent.

Scenario 1 (CNRM-CM5, RCP 4.5)	Scenario 2 (MIROC-ESM, RCP 8.5)	Scenario 3 (MIROC-ESM, RCP 8.5, Restoration)
Warm and Wet	Hot and Dry	Hot and Dry
Low Emissions	High Emissions	High Emissions
Land conversion continues at current rates	Land conversion continues at current rates	There is active restoration of fallowed croplands in the central valley and aggressive land restoration and increased protections
Precipitation increase and become more variable and extreme, leading to more heavy precipitation events, and food spoilage	Increases in suitable habitat and more intense droughts (both duration and intensity)	Increases in suitable habitat and more intense droughts (both duration and intensity)
Increases in precipitation extremes, meaning droughts can still occur between periods of heavy precipitation	Increased precipitation extremes and stochastic weather patterns, meaning drought years can be punctuated by heavy rainfall events	Increased precipitation extremes and stochastic weather patterns, meaning drought years can be punctuated by heavy rainfall events

Table 9. Three scenarios used for predicting the future condition of the giant kangaroo rat. The IPCC emissions scenario used for evaluating each future scenario are included in parentheses below the scenario titles.

Analysis of Future Scenarios

Future conditions were projected for each geographic unit based on the variations in precipitation, climate, extent of suitable habitat, and restoration as specified in our scenarios. We predicted changes in four of the five habitat needs, and two demographic factors described in our current condition analysis. The habitat factor of slope was held constant under all future scenarios, as it is not expected to substantially change under any scenario. We assessed changes related to habitat factors by making qualitative assumptions about habitat suitability and land protections, and made changes to demographic factors in accordance with related changes in habitat in the various scenarios.

Winter precipitation is difficult to predict in future scenarios, so assumptions were made under all future conditions. In Scenario 1, we expected that warm and wet conditions would increase winter rains, leading to increased primary productivity and vegetative growth. This would increase the growth of both native and non-native plant growth. Giant kangaroo rats feed on both native and non-native seed-producing plants, so under this scenario, high winter precipitation would benefit the species. Carrying this assumption forward, all categories for winter precipitation were increased under scenario 1. Under scenarios 2 and 3, intense droughts are projected to increase in both duration and intensity. This would decrease overall primary productivity, and the species would be assumed to respond negatively. Therefore, future winter precipitation was lowered by one level under both of the remaining future scenarios.

Summer precipitation is also difficult to predict, and similar assumptions were necessary. Under scenario 1, all summer precipitation is likely to increase, decreasing the overall suitability of habitat during the summer. Plants would still senesce in the summer months, but increased precipitation would spoil food stores, leading to decreased health and death for individual giant kangaroo rats. Under future scenarios 2 and 3, summer precipitation would decrease, meaning summers would be hotter and dryer. Because giant kangaroo rats are already adapted for hot, dry summers, it is not likely that they would be severely, negatively impacted by these changes during the summer months. Habitat suitability models confirm, that under RCP 8.5 emission scenarios, the suitable range of the giant kangaroo rat is expected to remain similar or even expand (Widick and Bean 2019, pp. 7–9).

Habitat connectivity among giant kangaroo rat populations has been decreasing throughout recent history. This trend is projected to increase into the foreseeable future. Under scenarios 1 and 2, we assumed if trends stayed the same, connectivity would decrease for all populations by one level, for areas which are not already under protection. Under scenario 3, we assumed that aggressive land retirement under SGMA and efforts from conservation organizations could increase habitat connectivity by one level.

Land protection was changed only for Scenario 3, where we assumed protections would increase under aggressive restoration and protection efforts.

We made changes to demographic factors in relation to expected changes to habitat factors. Although we used frequency of occupancy in our current condition estimates, it was not appropriate to project this metric into the future as it is not possible to project future occupancy with any degree of accuracy. Therefore, we relied on population trend to project demographics into the future. We did this using information based on past trends and responses of the species to changes in the environment.

Under scenario 1, we assumed that most categories would be lowered by one level. Winter precipitation would remain the same, while summer precipitation would increase, inversely lowering the condition of this category. Habitat connectivity and land protection would be lowered by one level because development would continue at current rates, further fragmenting habitat and reducing connectivity.

Under scenario 2, we also assumed condition would decrease by one level, due to continued habitat loss and degradation. Under hot and dry conditions, we assumed that winter precipitation would be less, and droughts would become more intense, longer, and more frequent. Summer precipitation would become less frequent, meaning conditions for this category would improve. Habitat connectivity and land protection would each be lowered by one level, as we do not expect current rates of land protection to change under this scenario.

Under scenario 3 we assumed that winter precipitation would be lowered by one level, as droughts would increase in severity and frequency. However, we assumed that both habitat connectivity and land protection would increase by one level due to increased habitat restoration, which would increase both habitat connectivity and land protection categories.

Conditions throughout the range of the giant kangaroo rat are projected to change under all scenarios (Table 12). There are uncertainties associated with all of our projections; these are the best estimates of future changes based on the best available data. The species is projected to decline in scenario 1 and 2, where climate becomes more unstable and humans continue to alter natural habitats. However, scenario 3 shows moderate increases to habitat and population trends, mostly due to increased conservation actions. Within this scenario, changes to climate are mitigated by restoration of habitat throughout the range.

Geographic Unit	Scenario 1 (Warm and Wet)	Scenario 2 (Hot and Dry)	Scenario 3 (Hot and Dry with Restoration)
Panoche	Low	Moderate	Moderate
Kettleman Hills	Low	Low	Moderate
San Juan Creek Valley	Low	Low	Moderate
Cuyama Valley	Low	Low	Low
Western Kern County	Low	Low	Moderate
Carrizo Plain Natural Area	Low	Moderate	High

Table 10. Summary of the overall condition scores predicted for the giant kangaroo rat geographic units under three future scenarios. Analysis units can be in overall low, moderate, or high condition. We give descriptions of these categories in **Factors influencing viability**.

CHAPTER 5: SPECIES VIABILITY

We have considered what the giant kangaroo rat needs for viability (Chapter 2) and evaluated the species' current condition concerning those needs (Chapter 3). We also forecast how the species' status might change in the future under three different scenarios (Chapter 4). In this chapter, we synthesize the results from our historical, current, and future analyses and discuss the potential consequences for the future viability of the giant kangaroo rat. We assess the viability of the species by evaluating the ability of the species to maintain a sufficient number and distribution of healthy populations to withstand environmental stochasticity (resiliency), catastrophic events (redundancy), and changes in its environment (representation) into the future.

Resiliency

Resiliency is the populations' ability to tolerate natural, annual variation (stochasticity) in their environment and recover from periodic disturbance.

Throughout the latter half of the 20th century, humans converted large portions of the giant kangaroo rats' habitat to agriculture and urban areas. Populations decreased rapidly in response to habitat loss and fragmentation. While there is little data on habitat condition and population trends before land conversion, evidence suggests historical populations had high resiliency.

Because there is no accurate, historical baseline to which we can compare, our analysis of the giant kangaroo rat's current condition and resiliency is limited to current geographic units, fragmented, isolated, and increasingly small habitat patches in the range. Best estimates suggest giant kangaroo rats exist on less than five percent of their historical range. The recovery plan identifies six geographic units throughout the range of the species where the species continues to persist. Based on the relevant factors evaluated in our analysis, only one of these units (Carrizo Plain Natural Area) is currently in high condition. It is important to note that populations of giant kangaroo rats on the Carrizo Plain are on the largest, continuous habitat with species-specific management. Once the habitat is protected, connectivity can increase, and populations might no longer be isolated. In this case, many of the adverse effects of demographic and environmental stochasticity might no longer pose a threat to the species, and populations are more likely to be stable. Currently, only one geographic unit (Carrizo Plain Natural Area) is well equipped to withstand stochastic variation, leaving the other five vulnerable to the effects of continued land conversion and climate change.

The predictions of future conditions vary for each of our three condition scenarios. Under predicted climate change projections and current land management trends, resiliency is likely to decrease for two of our scenarios within all geographic units (Table 12). However, if the land is converted and managed for the species, future conditions could improve for the species (Scenario 3).

Redundancy

Redundancy is the ability of a species to withstand catastrophic events. Redundancy is the duplication and distribution of populations across the range of the species.

The giant kangaroo rat is found only in south-central California, on the western slopes of the San Joaquin Valley, the Carrizo and Elkhorn Plains, and the Cuyama Valley. Before European settlement, the abundance of populations throughout the range of the giant kangaroo rat is unknown, but experts believe they were common (Grinnell 1922; Grinnell 1932). Most of its historical habitat is now in agriculture production or has been urbanized throughout the range of the species. Where the species does exist, abundance fluctuates or remains uncertain. The largest populations of giant kangaroo rats exist in both the extreme northern and southern parts of the range; in the Ciervo-Panoche and Carrizo Plain, respectively. These populations represent unique genetic lineages, and together increase the redundancy of the species. If either one became extinct during a catastrophic event, such as a wildfire or earthquake, the species' redundancy would decline.

Under the future scenarios, many of the geographic units would be in low condition. Should this happen, or should populations become locally extirpated, redundant variation throughout the range might no longer be possible. Land protections and restorations can mitigate the effects on populations from climatic change, and in scenario 3, many of the populations are in higher conditions than they are currently. This means extirpation would be less likely, even with the effects of climate change, with increased stochastic events.

Representation

Representation is the ability of a species to adapt catastrophic events, or to changing physical (climate, habitat) and biological (diseases, predators) conditions.

A species' representation is measured by assessing the genetic, morphological, behavioral, and ecological diversity within and among populations across its range. The more representation, or diversity, a species has, the more likely it is to persist in changing environments. Within the range, giant kangaroo rats occupied a variety of grassland, desert, scrub, and upland habitats. Precipitation varies among these habitats, being more mesic in the northern and western (coastal) portions of the former range. Genetic diversity appears to remain high throughout the range of the giant kangaroo rat. It is uncertain how much genetic diversity is already lost, however.

Gene flow is not possible across the range of the species and current populations appear to be isolated. Throughout most of the giant kangaroo rat range, precincts are not as abundant or dense as they once were, and populations continue to fluctuate throughout climatic events. In protected areas, population density is probably as high as they were before widespread agriculture. Populations still exist in a variety of habitats throughout the range, showing a moderate amount of representation. Giant kangaroo rat populations have persisted throughout their range during the most recent cycles of drought (2012-2016) and massive rainfall events (2018-2019). However, population numbers are currently low throughout most of the range. Those in the Carrizo Plain are moderate, despite the recent climatic events.

Under future scenarios, representation is likely to decrease under scenarios 1 and 2, due to declining conditions across the range. As conditions decline, extirpation becomes more likely, reducing the ability of a species to withstand stochastic events. Under scenario 3, representation is likely to increase across the range, should land protection be increased.

Synopsis of Viability

Viability is the ability of a species to sustain populations over time. Species that exhibit high resiliency, redundancy, and representation are more viable than those that do not.

The giant kangaroo rat is an endangered species. Habitat loss and broad-scale rodenticide applications were the main stressors responsible for the decline of the species. Since the time of listing, populations have increased in some areas, while diminishing in others. Abundances have fluctuated annually and with climatic events. Currently, three of the geographic units are in a low condition, two are in moderate condition, and one is in high condition. It is essential to acknowledge that we do not have information on the current occupancy for the unit in some areas. Populations are still distributed throughout the range, exist in the same breadth of habitats as they did historically, and show high genetic diversity and ability to rebound from climatic extremes, demonstrating redundancy and representation. Resiliency for the species is high on the Carrizo Plain but low in many other areas of the range.

We forecasted the future viability of the species by predicting the responses of our geographic unit conditions under three future scenarios 50 years into the future. Under two scenarios, all but one unit (the Carrizo Plain) is at risk of population decline. These scenarios would represent a significant range contraction for the species, and viability would likely decline. Land protection and management in scenario 3 improves the condition of the species and increases viability. It is important to note that the Carrizo Plain is the largest, contiguous habitat for the species, aspects which help to buffer against the effects of future threats. Some populations of giant kangaroo rats on the Carrizo Plain continue to be threatened by cannabis operations, oil development, or other human activities. However, most of the threats to giant kangaroo rats are outside of the Carrizo Plain National Monument, which is protected (Bean *in litt.* 2020). For the species to persist in all portions of the range, additional habitat protection, and land management might be needed to protect the species in perpetuity.

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