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# Stephens' Kangaroo Rat Rangewide Management and Monitoring Plan

March 2021

Prepared by
Conservation Biology Institute for Bureau of Land Management and Riverside County Habitat Conservation Agency

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# Foreword

P. Hester, Riverside County Habitat Conservation Agency

The Riverside County Habitat Conservation Agency (RCHCA) is a Joint Powers Authority (JPA) composed of 10 cities and Riverside County. In 1988, Stephens' kangaroo rat (SKR) was listed as Endangered under the Endangered Species Act (ESA). The SKR Habitat Conservation Plan (SKR HCP) was drafted as a result of this listing, and the RCHCA was formed in 1996 to plan, design, and implement the SKR HCP. The RCHCA manages conserved and open space lands for SKR in Riverside County, which defines our conservation, coordination, education, and collaboration mission.

In perspective, a single species HCP appears straightforward, involving efforts to adopt policies and procedures, protect habitat, and manage threats. However, it is much more complex and challenging, requiring concerted efforts to protect the ecosystem, monitor actions and their effects, demonstrate increased population numbers, and decrease environmental threats. It also entails implementing defensible scientific strategies to sustain populations and demonstrate success into the future. To further complicate this effort, SKR has a geographic range that crosses jurisdictional boundaries requiring federal, state, and local government; military establishments; and private landowners to agree, work together, and dedicate funding. Without this level of coordination, there is no way to recover SKR effectively.

Various agencies operate under HCPs and other regulatory documents that require the protection and management of SKR populations. These agencies may have different objectives; however, they share the common goal of demonstrating species recovery, thereby reducing the regulatory burdens created by an ESA listing. The Department of the Interior Bureau of Land Management (BLM) provides national leadership to promote restoration and protection for fish and wildlife and their habitats. In fact, BLM manages more fish, wildlife, and plant habitat than any other federal or state agency in the United States. Like other agencies, BLM has a vested interest in SKR recovery, as it is a protected species under their management plans.

In partnership with the Department of Defense (DOD), BLM awarded a grant to the RCHCA in 2019 using the Recovery and Sustainment Partnership Initiative. This initiative identifies listed species that occur on BLM-managed public lands and military regions. The partnership aims to develop and promote effective species conservation and recovery efforts and determine how BLM could assist by implementing various management actions. One of the species whose recovery would provide increased flexibility for military activities is SKR, since it impacts DOD's ability to use portions of their bases to complete training operations. Using these funds, the RCHCA subcontracted with Conservation Biology Institute (CBI) because of their scientific expertise in facilitating and planning projects that involve a wide diversity of partners.

From this collaborative partnership, the Range Wide Species Management and Monitoring Plan (Plan) was developed. This Plan is unlike any other. It is a living document designed by real-world experts who outline their many years of experience and success in SKR management and monitoring. It is not intended to be prescriptive or to replace permitted planning documents; rather, its purpose is to offer proven strategies to assist in SKR recovery efforts and standardize methodologies allowing for more precise management and consistent reporting.

Our goal is for wildlife agencies, scientists, land managers, and anyone involved with SKR recovery to use it, refer to it, and recommend it to others. Please share your success with the methods demonstrated here and as we discover new technologies or information in the years to come, let us all continue to work together by updating this resourceful body of work.

# Acknowledgments

This project was funded by the California Desert District Office of the Bureau of Land Management (BLM) via an agreement with the Riverside County Habitat Conservation Agency (RCHCA) from a Department of Defense and Department of Interior Recovery and Sustainment Partnership grant. A Core Project Team collaborated to guide Plan development: Princess Hester, Director of Administration, RCHCA (Chair); Bradd Baskerville-Bridges, Listing and Recovery Division Supervisor, USFWS; Brendan Himelright, Fish and Wildlife Biologist, USFWS; James Gannon, Fire and Fuels Specialist, CA Desert Interagency Fire Program, BLM; Russell Scofield, Senior Natural Resource Advisor, BLM; Brian Shomo, Director of Natural Resources, RCHCA; Riana Fisher, Staff Analyst, RCHCA; Deanne DiPietro, Senior Science Coordinator, Conservation Biology Institute (CBI); Gwynne Corrigan, Director of Communications, CBI; Craig Thompson, Senior Scientist, CBI; and Wayne Spencer, Chief Scientist, CBI. Debra Shier, Associate Director, San Diego Zoo Wildlife Alliance, and Rachel Chock, Postdoctoral Associate, San Diego Zoo Wildlife Alliance, represented the San Diego Zoo Wildlife Alliance SKR Genetics Research Team.

An SKR Working Group provided technical input and advice throughout the process, and several Subgroups were convened to provide technical input on topics relating to Management Actions, Monitoring, and Data Management (see Appendix A: SKR Working Group and Subgroup Members). RCHCA provided overall leadership to the Project Team, the SKR Working Group, and the planning process. In addition to the above, we give special thanks to the following individuals for significant contributions to the ideas and contents of this document: Rachel Chock and Debra Shier, San Diego Zoo Wildlife Alliance, for contributions concerning SKR ecology, behavior, and genetic matters; Cheryl Brehme, USGS, for information and advice concerning SKR population monitoring; Stephen Montgomery for expert input on SKR biology, management, and monitoring; Will Miller, USFWS, for assistance with understanding PAO sampling and power analyses; Betsy Dionne, Riverside Conservation Authority, for information on RCA reserves; Kris Preston, USGS, for coordination with the San Diego Management and Monitoring Program; Jessie Vinje, CBI, for information on and coordination with the Montecito Ranch Reserve; Jennifer Price and Beth Principe, County of San Diego, for information and coordination with the San Diego County Department of Parks and Recreation; Christy Wolf, Peggy Wilcox, and Loni Beyer Wilson, U.S. Navy, for help understanding the unique role of military installations to SKR conservation; Harry Sandoval, RCHCA, for assistance with GIS and monitoring data matters; Susan Wynn, USFWS, for input on conservation matters in San Diego County. Heather Romsos, CBI, did the habitat modeling and prepared map figures for the document. Rebecca Degagne, CBI, did the remote sensing data acquisition and interpretation, deriving variables from satellite data for use in habitat models. Kai Foster, CBI, provided GIS and data sharing support.

# Glossary

It is important to clearly define some terms used in this document that may differ somewhat from general usage or because closely related terms could be confused. In text, glossary terms are bolded on first use or where emphasis is helpful.

### *Habitat Terms*

**Ecoregion.** A large ecologically and geographically defined area that supports a relatively distinct assemblage of natural communities and species. In this document, the geographic range of SKR was split into five SKR ecoregions by modifying an ecological subsection map (Cleland et al. 2007), using terrain and climate factors relevant to SKR biology.

**Habitat map.** A map produced by projecting the values calculated by a **habitat model** across a landscape. A habitat map may portray **habitat quality** or **habitat suitability**.

**Habitat model.** A statistical algorithm that calculates **habitat values** for a species based on mapped environmental variables, such as land cover and climate variables. This document uses a maximum entropy (MaxEnt) model to calculate SKR habitat values based on the values of environmental variables at verified SKR localities relative to random values across the landscape.

**Habitat quality.** The capability of a site to support SKR based on its environmental characteristics. It may be mapped by experts based on field evaluation or as the continuous numerical **habitat values** produced by a **habitat model**, and it may be classed into any number of finite categories (e.g., high, medium, low quality).

**Habitat unit.** A cluster of **suitable habitat** patches within 200 m (an easy SKR dispersal distance) of one another, which therefore may be collectively capable of supporting an interbreeding **subpopulation** of SKR.

**Habitat value.** A number on a continuous scale from 0 to 1.0 assigned by a statistical **habitat model** as an indicator or predicted **habitat quality** at a site.

**Population unit.** An SKR **habitat unit** that is known to support SKR and therefore assumed to support an SKR **subpopulation** for purposes of monitoring and research.

**Suitable (versus unsuitable) habitat.** Habitat predicted to be capable (versus not capable) of supporting SKR using an algorithm that splits continuous **habitat values** into exclusive classes using a threshold that balances potential errors of over-predicting or under-predicting whether SKR may be found there.

### *Habitat Feature Terms*

**Dispersal barrier.** Any habitat feature that prevents organisms from moving between habitat patches, such as a major freeway or canal that can't be crossed by SKR.

**Dispersal filter.** Any habitat feature that may impede, but not completely prevent, movements by organisms between habitat patches, such that occasional dispersal is possible. Examples include minor paved roads or suboptimal habitat between suitable SKR habitat patches.

**Movement (or dispersal) corridor.** Any more-or-less linear habitat feature that facilitates movements by organisms between habitat patches, such as dirt roads or trails used by SKR to move across unsuitable habitat areas.

**Road-crossing structure**. Any physical structure that may facilitate movements by organisms across roads, such as overpasses or under-crossings (e.g., bridges or culverts).

### *Population Monitoring Terms*

**Census population size.** The total number of individuals in a **population**, regardless of age, breeding status, etc.

**Discovery monitoring**. Presence-absence sampling of habitat units not currently known to be occupied by SKR using a combination of kangaroo sign surveys (e.g., burrows and scats) and trapping to confirm species (SKR vs DKR).

**Effective population size ($N_e$).** The size of an "idealized" population that would have the same rates of genetic change as a **census population** under study. Because effective population size ($N_e$) reflects the size of the breeding population (excluding nonbreeding individuals) and accounts for such demographic factors as uneven sex ratios, variance in the number of offspring among pairs, and overlapping generations, it is more informative concerning population risks like inbreeding depression or extinction than is census population size.

**Grid.** Also referred to as a sample plot or site, the grid is the basic sampling unit for SKR **occupancy** sampling that will also be used for other purposes, such as calculating a population density index and collecting hair samples for genetic analysis.

**Metapopulation.** A collection of **subpopulations** that are connected by at least occasional dispersal.

**Occupancy.** In population estimation, the proportion of area, patches, or sample units occupied by a species at a given time.

**Occupancy monitoring.** Collecting data on species presence or absence at sample units within habitat patches and using statistical techniques to estimate the **percent area occupied** by the species.

**Percent area occupied (PAO).** An estimate of the actual proportion of area, patches, or sample units occupied by a species which accounts for the likelihood that some sites are occupied even though the species was not detected there (i.e., when detection probability is < 1).

**Population.** The collection of individuals of a species within a defined geographic area, such as the entire species' range or within a particular habitat patch or reserve area.

**Population density.** The census number (or actual count) of individuals per unit area (e.g., individuals per acre).

**Population density index.** An ordinal (rather than cardinal or actual count) indicator of density per unit area (e.g., high, medium, low number of individuals per acre). Indices are generally easier to estimate with certainty than census numbers.

**Population unit.** An SKR **habitat unit** that is known to support SKR and therefore assumed to support an SKR **subpopulation** for purposes of monitoring and research.

**Subpopulation.** A collection of individuals that may be able to interbreed with one another without major constraints, such as **dispersal barriers**. Occasional dispersal amongst separate subpopulations (**or population units**) may connect them into a larger **metapopulation**.

### *Management Terms*

**Fire management plan.** A land management plan that specifies how both wildfire and prescribed fire will be managed for resource goals, including fire type, intensity, frequency, seasonality, control methods, avoidance areas, fuels treatments, and contingencies.

**Genetic augmentation**. Translocation of animals into an already occupied habitat area (either from a wild or captive population) in order to increase genetic diversity in the receiving population.

**Grazing management plan.** A land management plan that specifies the type, number, timing, and other characteristics of how livestock are managed on a landscape to achieve desired resource outcomes.

**Habitat management**. Any action intended to improve or sustain favorable SKR habitat characteristics by affecting vegetation composition or structure, soil characteristics, or ecological disturbance regimes.

**Reintroduction.** Human movement of animals into suitable but currently unoccupied habitat areas to re-establish a population following extirpation. May be done by **translocation** of animals from occupied to unoccupied areas, or by releasing animals from a captive population into the wild.

**Reserve.** Any land maintained as open space with some protection against development. This includes military installations that are managed consistent with maintaining resource values while supporting the military's primary mandate of defense readiness, even though military installations are not legally preserved for nature protection.

**Restoration.** The systematic application of a suite of habitat management techniques to convert an existing, generally undesired, ecological state to a different, desired, ecological state, such as converting Mediterranean annual grasslands to a native condition of perennial grasses and forbs.

**State Responsibility Area (SRA).** The portion of the State of California, exclusive of cities and federal land, in which the California Department of Forestry and Fire Protection is primarily responsible for the prevention and suppression of wildfires.

**Translocation.** Any human-mediated movement of animals from one location to another.

### *Genetic Terms*

**Adaptation.** A heritable attribute that increases an organism's evolutionary fitness (ability to survive and reproduce).

**Allele**. One of two or more alternative forms of a gene that arise by mutation and are found at the same place (a **locus**) on a chromosome.

**Allelic richness.** A measure of genetic diversity indicative of a population's long-term potential for adaptability and persistence based on the number of alleles in a genome.

**Fst.** A measure of the degree of genetic difference between two populations as a result of **genetic drift** or natural selection.

**Gene pool.** All of the genes in a breeding population; the collective genotype of a population.

**Genetic cluster.** A collection of populations whose **gene pools** have similarities that may reveal a shared evolutionary history.

**Genetic drift**. A random (i.e., not adaptive) change in gene pool frequencies in a population due to chance. The rate of drift tends to be inversely proportional to population size.

**Gene flow**. The introduction of genetic material from one population to another by interbreeding, thereby changing the gene pool of the receiving population.

**Genetic monitoring.** Sampling gene pools over time to track potential changes, such as **genetic drift** or **gene flow**.

**Genetic structure.** Systematic differences in gene pools among **subpopulations** due to limited gene flow between them.

**Heterozygosity.** The condition of having two different alleles at a locus in an individual's genome.

**Isolation by distance.** Genetic differences that increase with increasing distance between sample populations due to limited dispersal distances of a species relative to the size of the species' range.

**Locus**. A specific location on a chromosome which may have alternative **alleles**.

**Microsatellite markers.** Specific identified lengths of repetitive DNA in an organism's genome that have high mutation rates and are therefore useful for making inferences about historic gene flow, isolation, inbreeding, drift, or local adaptation.

### *Plan Implementation Terms*

**SKR Data Manager.** An organization or person responsible for aggregating and stewarding the SKR Rangewide Monitoring Database.

**SKR Implementation Team.** The group responsible for decision-making during implementation of this Plan on behalf of the **SKR Stakeholders**.

**SKR Stakeholders**. All people and agencies having an interest in SKR conservation issues.

**SKR Technical Team.** The team of SKR experts, researchers, and reserve managers that provides technical advice and guidance for Plan implementation.

**SKR Working Group.** The inclusive group of SKR experts, decision-makers, reserve managers, researchers, and stakeholders that participated in developing this Plan. Members are listed in Appendix A: SKR Working Group and Subgroup Members.

# 1. Introduction

This Stephens' Kangaroo Rat Rangewide Management and Monitoring Plan (Plan) summarizes new and existing information concerning the endangered Stephens' kangaroo rat (SKR; *Dipodomys stephensi*) and uses it to present comprehensive, rangewide SKR management and monitoring strategies. It is intended to help agencies responsible for SKR conservation be more efficient and effective in using their limited resources to systematically manage and track changes in SKR habitat quality, population numbers, and threats. It will also help these agencies coordinate their management actions more strategically to promote rangewide species conservation goals, because local SKR conservation actions within particular reserves or Habitat Conservation Areas can contribute to SKR conservation at broader scales.

This document was prepared by Conservation Biology Institute (CBI) working closely with an SKR Working Group having expert representation from the diverse suite of land owners and management entities responsible for SKR conservation. It is not a legally mandated or binding conservation plan, and it is not intended as a U.S. Fish and Wildlife Service SKR Recovery Plan. However, the contents of this management and monitoring document can serve as a foundation for a recovery plan or any other plan contributing to the conservation of SKR, and can be used by the regulatory agencies as guidance for decisions made under the Endangered Species Act or other relevant policies, rules, and regulations. The project was funded by the Bureau of Land Management via an agreement with the Riverside County Habitat Conservation Agency (RCHCA).

**SKR Working Group members** include representatives from Bureau of Land Management; California Department of Fish and Wildlife, Inland Deserts and South Coast Regions; California State Parks, San Jacinto Lake Perris; County of San Diego Department of Parks and Recreation; March Air Reserve Base; U.S. Marine Base Camp Pendleton; U.S. Naval Base Coronado, U.S. Naval Base Coronado Remote Training Site Warner Springs; Riverside County Habitat Conservation Agency; San Diego Zoo Global (now San Diego Zoo Wildlife Alliance), Institute of Conservation Research; The Nature Conservancy; University of California Riverside Motte Rimrock/Emerson Oaks Reserve; U.S. Forest Service; U.S. Geological Survey, San Diego Management and Monitoring Program; U.S. Fish and Wildlife Service, Carlsbad and Palm Springs Field Offices; Vista Irrigation District; Waste Management Inc., El Sobrante Landfill; Western Riverside County Regional Conservation Authority; and independent biologists Stephen Montgomery and Mark Pavelka (U.S. Fish and Wildlife Service, Retired). Please see Appendix A: SKR Working Group and Subgroup Members.

After presenting the background, context, and general approach for this SKR Rangewide Management and Monitoring Plan, this document presents the following interrelated components:

1. A review of **SKR Ecology** with focus on its habitat requirements and other information pertinent to SKR conservation.
2. An SKR **Habitat Model**, which presents a new method for mapping and tracking changes in SKR habitat distribution and quality based on environmental attributes.
3. Newly delineated SKR **Habitat Units** and **Population Units** based on the habitat model to serve as spatial sampling units for monitoring.
4. An SKR **Biogeographic Working Map**, which combines habitat model results, the SKR habitat and population units, and other spatial data as a platform for understanding, planning, and tracking important SKR spatial information, such as population distribution, genetic structure, and management and monitoring locations.
5. An SKR **Threats Assessment** based on a survey completed by land managers across a number of SKR reserves to augment existing understanding of threats at both the rangewide and local scales.
6. An SKR **Management Strategy** that provides a framework and guidance for SKR habitat management, population management (for example, via translocations or reintroductions), and threats mitigation (for example, by controlling exotic predators or light pollution) coordinated across the species range.
7. An SKR **Monitoring Strategy** that establishes a coordinated, rangewide framework and guidance for monitoring SKR populations, habitat distribution and quality, genetic diversity, and threats. It also provides guidance for research projects to compare the effectiveness of alternative management actions.
8. A **Data Management Strategy** that describes a framework and guidance for developing an integrated SKR Data Management System, which will build on existing SKR databases and provide guidelines for consistent data collection, collation, reporting, and sharing protocols.
9. A framework for a **Plan Coordination Structure** to coordinate management and monitoring decisions, fund raising, data sharing, and other critical issues during implementation.
10. Finally, **Recommendations and Next Steps** for important tasks that should be completed in the early phases of Plan implementation, such as convening the coordination groups and developing the Plan Coordination Structure, refining the SKR habitat and population units, detailing the monitoring program sampling design, and performing important research studies.

## 1.1. Background and Context

The SKR is a rare mammal in the family Heteromyidae[1] associated with grasslands and open scrub vegetation on loamy soils in southern California, or more specifically western Riverside County and northern San Diego County (Figure 1). Since its listing under both the California (1971) and US (1988) Endangered Species Acts[2], intensive conservation planning efforts have established numerous ecological reserves for SKR and other species. However, SKR reserves[3] have not been consistently managed and monitored, largely because they are scattered across multiple jurisdictions and land ownerships. In addition, a number of important SKR habitat areas are neither conserved nor managed to benefit SKR. Nevertheless, the US Fish and Wildlife Service is mandated to track overall population status and trends of listed species, and hence desires a systematic and comprehensive means of tracking SKR populations across the entire SKR range in this diverse geopolitical landscape.

In 1997 the US Fish and Wildlife Service produced a Draft Endangered Species Recovery Plan for SKR (U.S. Fish and Wildlife Service 1997), but the plan was never finalized. Since then, scientists and managers have learned much more about the species and its conservation needs. In addition, recent technological advances allow for new and better ways of mapping and monitoring habitat conditions at fine resolution using satellite imagery (Spencer and Romsos 2019). This document collates this new information and applies the satellite mapping technology to provide a platform for comprehensive reserve management and monitoring across the species range.

In 2019, the Bureau of Land Management (BLM) partnered with the Department of Defense (DOD) using the Recovery and Sustainment Partnership Initiative to identify listed species present on both BLM-managed public lands and military reservations that could benefit from BLM management actions and thus potentially reduce constraints to military operations on DOD lands. SKR occur on both BLM and DOD lands, and their presence constrains military training operations on military reservations. BLM therefore contracted with the Riverside County Habitat Conservation Agency (RCHCA) under the Good Neighbor Authority to support this Rangewide SKR Management and Monitoring Plan as well as other tasks furthering species recovery.

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[1] Heteromyid rodents (pocket mice, kangaroo rats, and kangaroo mice) have external, fur-lined cheek pouches or pockets, which they use for collecting and transporting food (mostly seeds). They are adapted to arid environments; most have elongated hind limbs and tails adapted for jumping movements, similar to kangaroos. They are primarily nocturnal, have superb hearing, live in burrows, can survive with little or no water, and bathe in sand and dust to control parasites and pelage oils and to communicate with their scent. They tend to have low reproductive rates for rodents of their body size.

[2] The SKR was federally listed as endangered in 1988 and was proposed for downlisting to threatened in 2020 (U.S. Fish and Wildlife Service 2020) but that change is not yet finalized.

[3] This document uses the term “reserve” broadly to include lands having some protection against development that are maintained in open space and may sustain natural resource values. This includes military installations that may be managed consistent with maintaining SKR or other resource values while also supporting the military’s primary mandate to maintain defense readiness, even though military installations are not technically nor legally preserved for nature protection.

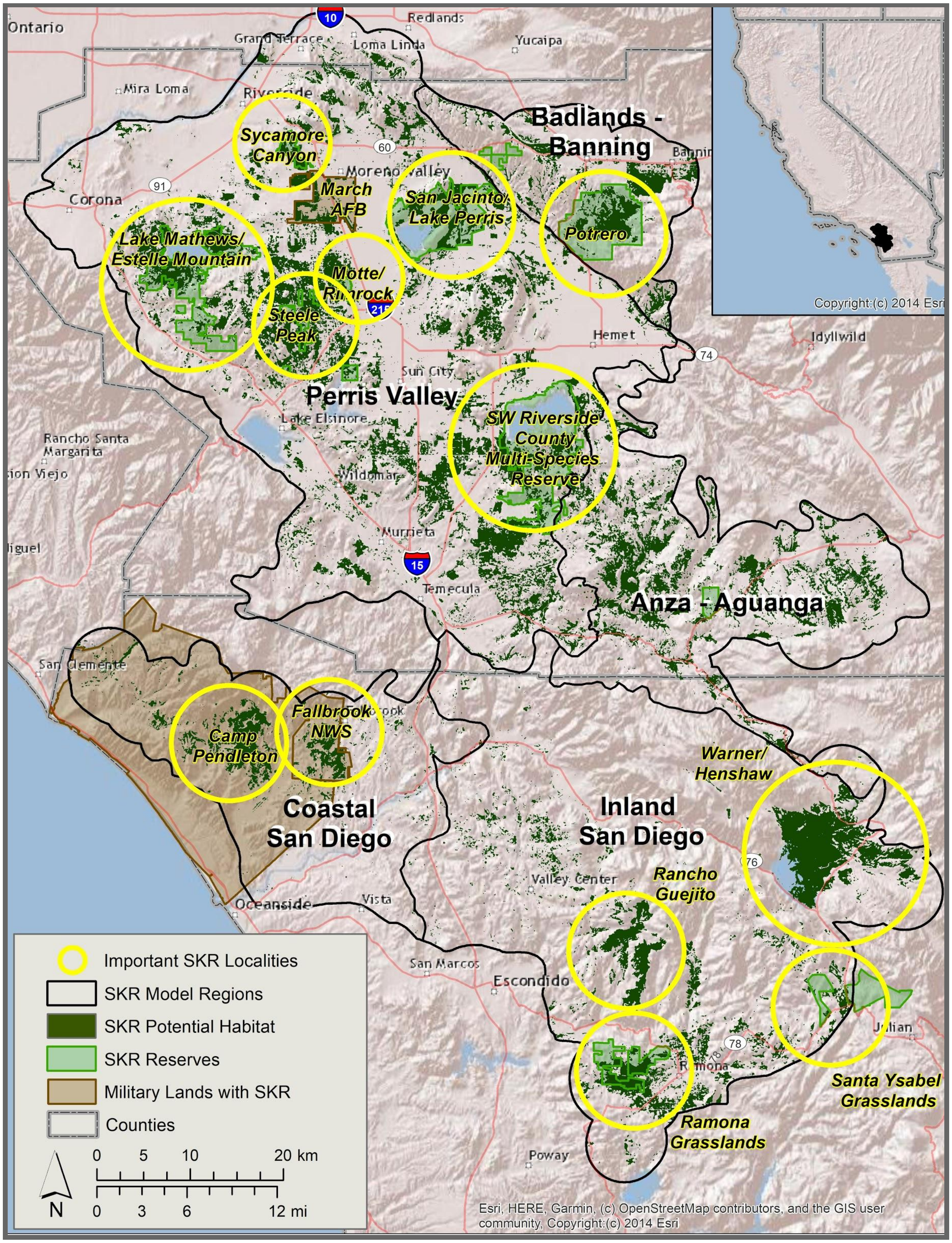


**Figure 1**. SKR Plan area showing modeled suitable (or potential) habitat, SKR reserves, important localities, and five subregions used for habitat modeling.

## 1.2. Approach

The SKR Rangewide Management and Monitoring Plan (Plan) integrates existing SKR management plans, monitoring protocols, and expert knowledge into a cohesive regional strategy using an updatable habitat suitability model as a foundation. It considers the species' biogeographic conditions, including patterns in the spatial distribution of potential and occupied habitat areas and SKR population size, distribution, and genetic diversity, while providing flexibility in implementation for the diverse land ownerships and management entities responsible for SKR conservation. It also considers temporal dynamics in these factors, such as how climate and weather may affect habitat quality, population density, and genetic diversity over time.

The Plan identifies priorities and standard methods to better coordinate SKR management to achieve rangewide conservation goals, and it recommends an interagency coordination structure led by an **SKR Implementation Team**. The Implementation Team (decision-makers) will get input from an **SKR Technical Team** (species experts and reserve managers) and **SKR Stakeholders** (others with an interest in SKR conservation). The Technical Team will regularly update and review SKR status and trends, as well as the effectiveness of management actions. This information will be used by the Implementation Team to make decisions about research, monitoring, and management priorities and to collaboratively seek funding for priority projects. The result is a science-informed **SKR Adaptive Management Cycle** that enables well-informed contributions to species recovery (Figure 2).

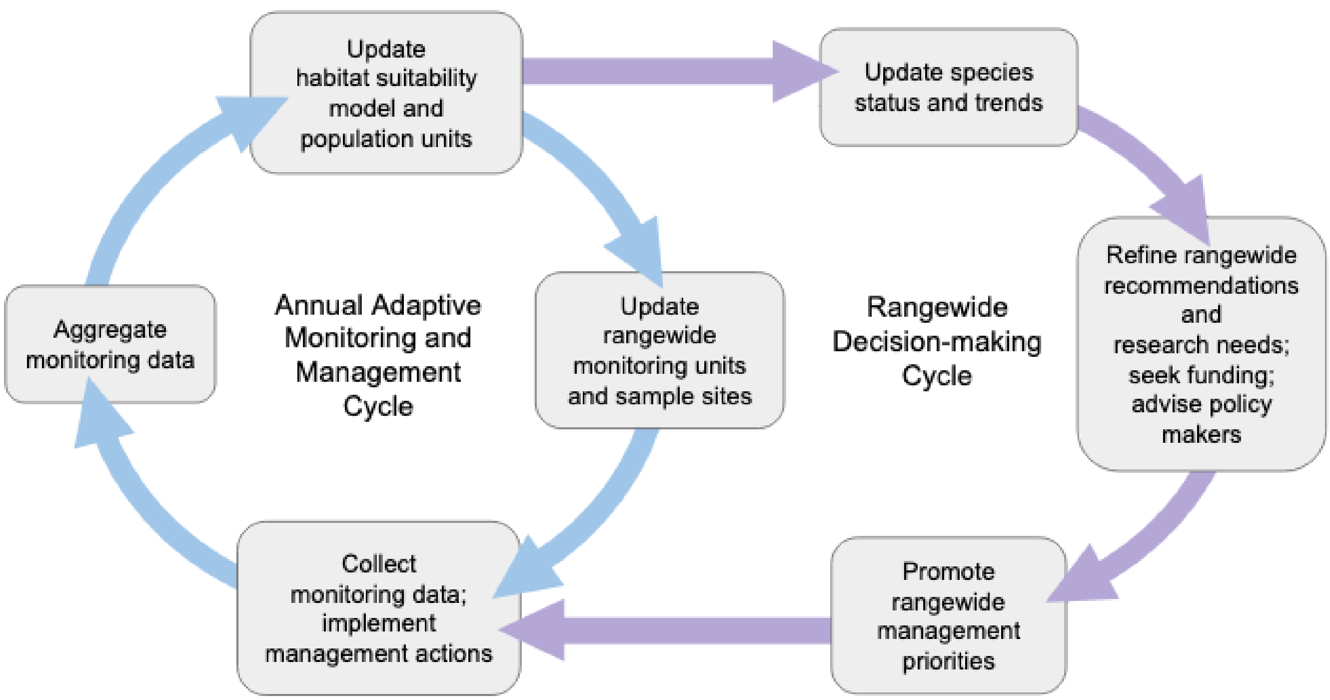


**Figure 2.** Steps in the SKR Adaptive Management Cycle. Annual monitoring conducted on SKR reserves enables updating of the database, models, sampling design, and management decisions. Decisions having rangewide implications are informed by monitoring results, research findings, and other lessons learned, and in turn advise management actions with rangewide priorities.

Here we briefly describe major Plan components that are elaborated on in subsequent chapters.

### 1.2.1. Use of Habitat Models and Delineating Population Units

The general nature of SKR habitat associations is well documented, but it has been difficult to capture these characteristics in an empirical habitat model that can be used to objectively map **habitat quality** over the species' range or to track changes in quality over time. We developed spatial models of SKR habitat values across the range based on SKR detection data and an array of environmental variables (e.g., climate, terrain, vegetation, and soil variables). Clear advantages of the new **habitat maps** is that they use variables derived at relatively fine resolution (20m) from freely available satellite imagery, and they can be regularly updated (e.g., annually) to track habitat changes due to management or other influences.

The Plan uses this new SKR habitat modeling system as a foundation for monitoring and management decisions. It can be used to map and track how habitat quality varies across space and time in response to management, weather, and other factors. By establishing correlations between predicted habitat quality and field-based SKR population metrics, the system can also be used to help estimate and track population distribution and abundance.

The habitat map was also used to delineate clusters of SKR habitat patches within dispersal distance of one another and that therefore may support local, interbreeding **subpopulations** in a **metapopulation** structure. These habitat clusters are defined as habitat units, and those known to be occupied by SKR are called population units. These draft habitat and population units can be refined and used as sampling units for purposes of allocating monitoring efforts.

### 1.2.2. Biogeographic Mapping and Genetic Considerations

The Plan combines the SKR habitat map and population units with other pertinent spatial information into an SKR **Biogeography Working Map** that can be used by SKR managers and researchers to understand the spatial context for management and monitoring efforts. The biogeographic map presents information concerning potential habitat and population distribution, land ownership and management responsibilities, terrain and climate influences, SKR population genetic patterns, and other pertinent spatial information that can be updated as conditions change. An important function of the map is to show patterns of fragmentation and connectivity of SKR habitat and populations, including where there may be barriers or impediments to species movements between habitat patches. Hence, the biogeography map is intended to be a dynamic working map that should be updated with changing conditions and used to help guide where monitoring efforts and management interventions may be most effective in tracking and recovering the SKR metapopulation.

Because habitat and population fragmentation represent major threats to SKR, the strategy uses the habitat maps and recent population genetic information to help identify where habitat restoration, translocations, or other actions could improve habitat and genetic connectivity. Patterns of SKR distribution and genetic diversity strongly suggest that, rangewide, SKR interact as a **metapopulation** (Hanski 1999), or perhaps more accurately as a set of independent metapopulations that are demographically isolated from one another by unsuitable habitat and dispersal barriers due to human land-use changes. We recommend developing a spatially explicit metapopulation dynamic model (e.g., using HEXSIM (Schumaker and Brookes 2018)) to investigate how SKR subpopulations interact across the range and to inform where management interventions, such as active translocations, may be necessary to sustain genetic diversity and overall population viability.

### 1.2.3. Threats Assessment

Although rangewide threats to SKR are already well documented (USFWS 2020), this document refines our understanding using comprehensive threats assessments completed by preserve managers across eight SKR preserve areas (see Chapter 6, SKR Threats Assessment and Appendix D: Threats Survey Summary). The threats assessment format was developed by the SKR Working Group to identify and define all possible threats to individual SKR and subpopulations at the preserve level, including both existing known threats and potential future threats (e.g., under climate change). The preserve-level assessments also address current management and mitigation strategies as well as factors that constrain management actions. The results of these preserve-level assessments were summarized to better understand the pervasiveness and importance of various threats across the species' range and thus to aid prioritization of management, monitoring, and research actions.

### 1.2.4. Management Strategy

The Management Strategy identifies and promotes effective tools for managing SKR habitat, populations, and threats both within and among preserves. Habitat management using grazing, fire, and other tools is intended to promote the open, forb-dominated conditions preferred by SKR. Population management may include translocations, captive breeding, and reintroductions to re-establish extirpated populations or to bolster genetic diversity and demographic viability of subpopulations. Threat management addresses means of mitigating adverse effects of specific threats, such as nonnative predators, dispersal barriers, or flooding. The management strategy provides for coordinated species management across ownership boundaries by helping prioritize where management investments will best promote species conservation and recovery goals at the rangewide scale.

### 1.2.5. Monitoring Strategy

The Monitoring Strategy provides a framework for a standardized sampling design to track changes in SKR habitat and population across the range, based on the approach already developed, tested, and refined on Marine Corps Base Camp Pendleton (Brehme et al. 2006, 2011, NFECSD 2018). The draft habitat units and population units delineated using the dynamic habitat quality map provide a spatial foundation for quantifying the amount of suitable and occupied potential habitat; and by correlating field measures of SKR **occupancy**, **density**, or **effective population size** (from genetic monitoring) with habitat quality, the map can be used to track rangewide patterns in SKR abundance.

Monitoring of **percent area occupied (PAO)** (MacKenzie et al. 2002) by SKR will ideally be conducted across all occupied habitat units (i.e., the population units defined in Chapter 4) using standardized trapping grids, but the number of sampling units and the specific design of the trapping grids and schedule need to balance precision of the occupancy estimates (i.e., how much certainty is required?) and the feasibility of implementing the field sampling given available personnel, funding, access, and other constraints. Where PAO methods are already being employed (e.g., Marine Corps Base Camp Pendleton), the methods should also accommodate a smooth transition to a rangewide sampling program without disrupting data continuity.

With these considerations in mind, and supported by a preliminary PAO power analysis, an initial sampling design will be developed by the SKR Technical Team during the first year of Plan implementation. Once this initial sampling design is applied in the field and the data analyzed, the methods will be reassessed and refined as needed. Once a standardized approach is put into practice for several years, the monitoring program should continue to be periodically (about every 5 years) reviewed and adjusted by the SKR Technical Team. This evaluation should consider accumulating knowledge to ensure monitoring is using the best available tools and techniques, is adapting to changes in SKR distribution and reserve status, and is efficiently and effectively achieving Plan goals.

In addition to PAO sampling in known, occupied population units, a portion of those habitat units for which SKR occupancy is unknown will be sampled each year ("discovery" or "sentinel site" sampling) to improve understanding of population trends (for example, to document colonization of previously unoccupied sites). Kangaroo rat sign surveys (identifying burrows, trails, scats, tracks, or other signs) will be used to identify likely occupied areas, followed by trapping to verify species (SKR or DKR) where signs are found. Although kangaroo rat sign surveys (e.g., burrow count transects) are unreliable for density estimates, they are cost-effective for establishing presence of kangaroo rats and identifying where new population units should be added for PAO monitoring.

The same sample sites (trapping grids) used for PAO monitoring may also be used to calculate local **density** indices, based on capture-recapture protocols that consider habitat metrics as "covariates" to better understand how occupancy and density reflect habitat qualities.

The strategy also recommends **genetic monitoring** to track **effective population size** as well as status and trends in genetic diversity, relatedness, inbreeding, and population structure. Hair samples will be extracted from SKR captured during occupancy monitoring efforts for genetic research and monitoring. During Plan implementation, genetic monitoring of effective population size may prove more informative and cost effective than estimating population density from capture-recapture trapping, and might ultimately replace that method. This could shorten the trapping duration needed at sample sites for PAO and density estimates, potentially allowing some reallocation of budget to other SKR conservation priorities.

## 1.2.6. Data Management Strategy

The SKR Data Management Strategy is a framework for an integrated SKR **Data Management System**, which will build on existing SKR data collection efforts and provide standards for consistent data collection and reporting. Standardization will facilitate quality assurance, data aggregation, access, and analysis across the range. The SKR Data Management Strategy is an essential component of the SKR Monitoring Strategy, and together these support the understanding of how SKR habitat and populations are varying across space and time in response to management and other factors so that conservation actions can be adjusted on a continual basis.

## 1.2.7. Coordination Structure

This SKR Management and Monitoring Plan recommends and sets in motion a collaborative, multi-agency approach to ongoing rangewide SKR management and monitoring. The goal is to improve the efficiency and cost effectiveness of actions that further species recovery across the range and for agencies to collectively pursue additional funding to support research and other important tasks. To make this possible, a Coordination Structure is needed to coordinate stakeholders, facilitate data stewardship and analysis, and oversee decision-making and strategic fund-raising. We suggest a framework for such a structure with the teams and stakeholders described in Chapter 10.

# 2. SKR Ecology

SKR is a nocturnal, burrowing, seed-eating rodent of open "forblands" or "California prairie" (but usually classified as grasslands, which may be misleading[4]) and sparse scrub, on gentle slopes with loamy soils, in cismontane Riverside and San Diego counties. Like other kangaroo rat species, it can survive with little or no free water due to highly efficient metabolic water production and use. It feeds primarily on the seeds and shoots of grasses, forbs, and shrubs, supplemented occasionally with insects. It uses external, fur-lined cheek pouches to transport seeds from collection sites to burrows or caches, which presumably minimizes moisture loss via the mouth.

Due to its kangaroo-like movements, SKR requires open ground conditions with some exposed soil, which it also uses for "dust bathing" to control external parasites, remove excess oils from its pelage, and communicate via scents. Kangaroo rats also "foot drum" to communicate over longer distances.

SKR are relatively sedentary, with young usually establishing home ranges close to where they were born (generally within ~30m), but are capable of long-distance dispersal movements (>400m or perhaps even >1km) in appropriate habitats or along dirt roads or trails. Female SKR tend to occupy home ranges with minimal intrasexual overlap, whereas the larger home ranges of males tend to overlap with one another and with multiple females. Reproductive rates are rather low for a rodent of their body size, but females are capable of producing multiple (2-3) litters in years with favorable conditions. SKR population density can vary substantially over space and time, and populations tend to be patchily distributed within suitable habitat.

SKR sometimes co-occur with the more widespread Dulzura kangaroo rat (DKR; *Dipodomys simulans*), at ecotones between grassland and shrubland but SKR is thought to be competitively dominant and may restrict the DKR to shrubbier cover where the two species come in contact (Bleich and Price 1995). SKR are preyed upon by a variety of snakes, owls, weasels, and coyotes, and perhaps occasionally by badgers. Their burrow systems typically have 3-5 burrow entrances, are often improved from those first created by pocket gophers, and may be shared with a wide array of other rodents, invertebrates, and reptiles. Due to its foraging effects and burrowing activities, SKR may be considered a "keystone species" that has a strong influence on their ecological community via effects on vegetation composition and structure (Brock and Kelt 2004a) and their maintenance of burrow systems also used by other species.

## 2.1. Distribution and Population Genetics

SKR has a very restricted geographic range for a rodent of its body size. Historically it was found in western Riverside County, northern San Diego County, and extreme southwestern San Bernardino County. It currently occurs in widely scattered grasslands, perhaps more appropriately called forbland

[4] The label "grassland" generally applied to herbaceous vegetation in California has been debated as misleading by plant ecologists, particularly from an ecosystem conservation perspective (see the special issue of Fremontia, volume 39:2-3, May and September 2011, for a fairly thorough treatment of this topic). Today's "grasslands" in California may be dominated by nonnative, annual Mediterranean grasses, but prior to European settlement they were dominated by diverse forbs between widely spaced perennial bunch grasses. This probably was more akin to the preferred SKR habitat condition, which supports a higher proportion and diversity of annual forbs than annual grasses. This document nevertheless uses the term grassland in keeping with common usage.

or California prairie[3], and very open scrub habitats in western Riverside and northern San Diego counties. Scattered populations are found across the Perris Valley and the Anza area in Riverside County; on Marine Corps Base Camp Pendleton and Fallbrook Naval Weapons Station in northwest San Diego County; and on scattered inland grasslands in the Warner Basin/Lake Henshaw area, the Santa Maria Valley (Ramona Grasslands), and in and near Rancho Guejito near Escondido. Former populations in southwestern San Bernardino County and in the Oceanside/Bonsall area of San Diego County are apparently extirpated, as are numerous other historical sites that have been lost to development. Most remaining populations are separated by human development and other unsuitable habitats, and many are demographically and genetically isolated from others.

The current distribution of suitable SKR habitat and populations, along with existing information on their genetic structure, suggest that the rangewide population of SKR functions as a collection of regional metapopulations, with little if any gene flow between them. For example, SKR on Camp Pendleton and Fallbrook Naval Weapons Station may comprise one isolated metapopulation, and SKR in inland San Diego County (Rancho Guejito, Ramona, and Warner Basin) may represent several isolated subpopulations or possibly one or two metapopulations.

Researchers at San Diego Zoo's Institute for Conservation Research (ICR) have demonstrated that SKR **allelic richness** (a measure of genetic diversity) declines as one moves southward from the northern Perris Valley region to the southern populations in San Diego County, suggesting that the species expanded southward from an ancestral population in the northern part of the range. These results also suggest that SKR once had a more continuous distribution that has undergone recent habitat fragmentation, such that the current **metapopulation** structure of SKR is a relatively recent phenomenon created by human land-use changes. Reduced dispersal and genetic mixing have led to recent genetic isolation and local **genetic drift** (Shier and Navarro 2016). Ongoing research is exploring changes in historic and contemporary connectivity across the range of SKR. Linking patterns of genetic differentiation to landcover features will reveal how habitat fragmentation has impacted the species and inform mitigation and translocation efforts.

## 2.2. Habitat

This section describes what is known about SKR habitat characteristics at relatively fine resolution in the field. This information was considered in creating and selecting variables used to develop the statistical habitat value model described below, which maps SKR habitat consistently across the species geographic range.

SKR is a habitat specialist that occupies open grasslands[3] with abundant native and non-native annual forbs, or sparse coastal sage scrub with shrub cover less than about 30%, and extensive bare ground for most of the year (Spencer et al. 2017). Before the rapid conversion to what is called California annual grasslands following introduction of livestock (cattle, sheep, and horses) to California, SKR habitat was more appropriately termed "California prairie," which probably provided superior habitat conditions to those found today. California prairies were dominated by a diverse and abundant array of native annual forbs (flowering herbaceous plants) between widely spaced native, perennial bunch grasses, especially purple needlegrass (*Stipa pulchra*) (Minnich 2008), (Stromberg et al. 2007). Field observations reveal that SKR are currently strongly associated with native and nonnative forb-dominated habitats that green up, flower, and set seed in spring (with April generally having maximum vegetation greenness and moistness), but then rapidly dry out and disarticulate over summer, leaving abundant open ground and bare soil conditions. This vegetative composition and dynamic now largely depends in some areas on the very cattle grazing that likely ravaged the perennial bunchgrasses and spurred an explosion of non-native annual grasses in southern California (Stromberg et al. 2007). Elsewhere, favorable SKR habitat conditions may be maintained by sheep grazing, fire, or other disturbance factors. Restoring original native vegetation conditions is generally considered infeasible due to the overwhelming competitive advantage of annual grasses, due to their dominance in the soil seed bank and ability to germinate before most native annual forbs. Nevertheless, understanding the nature of the SKR's original habitat can help managers achieve some of the characteristics that made it suitable, such as abundant forbs and lack of grass thatch.

Typical SKR habitat today supports both native and non-native forbs, such as filaree (*Erodium* spp.), dove weed (*Croton setiger*), tarplant (*Deinandra fasciculata*, *D. paniculata*), and goldfields (*Lasthenia* spp.). The SKR's diet is dominated by seeds produced by such annual forbs; and the open, bare-ground conditions that result as the forbs dry out and disarticulate over summer creates the open, bare soil conditions that SKR prefer for their highly evolved modes of locomotion (e.g., bounding), grooming and communication (e.g., "sand-bathing"), and other peculiarities of their ecology. In contrast, the dense thatch buildup of annual Mediterranean grasses, especially where disturbance by grazing or fire is absent, impedes SKR movements and their ability to forage for seeds or interact with one another. Although SKR thrive in habitats devoid of shrubs and dominated by spring annuals, it is possible that sparse shrubs (e.g., *Artemisia*, *Eriogonum*) and summer annuals (e.g., *Croton, Deinandra*) may contribute a greater diversity of seasonal foods for SKR.

The soils in occupied SKR habitat are usually loamy and friable, which facilitates burrowing. Rarely are soils used by SKR high in clay or rock content, which make burrowing difficult, or very sandy, in which burrows may collapse. SKR will use suboptimal soils (e.g., higher in clay or rock content) where better soils are not available and other factors contribute to favorable conditions. For example, pocket gophers and ground squirrels are stronger burrowers than kangaroo rats, and their burrowing in heavier clay soils can facilitate later use by SKR.

## 2.3. Sociality and Burrow Use

SKR have been considered to be generally solitary, like most other kangaroo rat species. While some research suggests that SKR exhibit a higher incidence of burrow sharing amongst individuals than observed in any other species (Brock and Kelt 2004b) these results were based on trapping data and have not been verified by radiotelemetry. In fact, data from both behavioral observations of marked individuals and radiotelemetry of more than 120 individuals at translocation release sites across 3 years indicate that SKR live alone like other kangaroo rats and defend territories from conspecifics (Shier Unpublished, 2009, Shier and Swaisgood 2012). While SKR are solitary, they are not asocial. SKR interact regularly with familiar neighbors and respond less aggressively to familiar neighbors than to unfamiliar animals, a phenomenon known as the "dear enemy" effect (Ydenberg et al. 1988, Temeles 1994). Moreover, results from an experimentally controlled translocation showed that immediately following relocation, SKR translocated in intact neighbor groups fought with conspecifics less and foraged and established burrows more quickly than SKR translocated with unfamiliar neighbors and over subsequent months, these individuals were more likely to survive and reproduce (Shier 2009, Shier and Swaisgood 2012).

An SKR burrow complex may have several to many entrances, with the number varying among locations, presumably due to soil characteristics or the burrowing activities of gophers or ground squirrels that may originally create the burrows. The density of burrow entrances roughly correlates with population density at a location, but the correlation breaks down when considering multiple locations (Brock and Kelt 2004b). Thus, burrow counts on plots or along transects offer a quick, coarse means of assessing population presence and perhaps density, but they are not reliable for accurate density estimates across the species' range.

## 2.4. Diet and Foraging

Like other kangaroo rats, SKR are primarily granivorous, feeding on the seeds and young shoots of annual forbs (e.g., *Erodium* and *Croton*), grasses (e.g., *Bromus*), and some shrubs (e.g., *Artemisia* and *Eriogonum*). They will also occasionally ingest insects (e.g., ants and beetles) [Citation error]. SKR forage for seeds by smell, whether the seeds are on or below the soil surface, and they will readily clip seed heads from low-growing plants (W. Spencer, personal observations). When seeds are abundant, SKR will store them both in their burrows and in shallow caches scattered throughout their home ranges. Kangaroo rats are famous for avoiding bright moonlight or artificial lights when foraging in exposed areas, although they may forage where shrub cover provides some shade (S. Montgomery, personal communication). SKR have been observed to cease above-ground activity when potential predators are observed (W. Spencer, personal observations), although S. Montgomery (personal communication) did not see obvious changes in SKR behavior after hearing barn owls overhead on Marine Corps Base Camp Pendleton.

## 2.5. Space-use Patterns

Even in suitable habitat, SKR may be patchily distributed, with clusters of burrows often separated by unoccupied areas; and occupied areas may shift on the landscape over time. SKR are strong dispersers, probably capable of colonizing habitat patches hundreds of meters or possibly >1km from other occupied habitats (Thomas 1975, O'Farrell and Uptain 1989, Price et al. 1994, Brock and Kelt 2004c), so long as the terrain is open and gentle enough to facilitate travel. However, they are territorial, establishing a home range and typically remain near their natal territory for life. Animals will often use dirt roads, trails, agricultural edges, or other open ground as travel corridors, but they avoid using gravel roads (O'Farrell and Uptain 1989, Price et al. 1994, Brock and Kelt 2004c). They occupy stable home ranges averaging about 0.2 ha (0.5 ac) for males and 0.1 ha (0.25 ac) for females. As in other kangaroo rat species, male home ranges tend to overlap with multiple females and can be irregular in shape, whereas female home ranges tend to be exclusive of other females and relatively circular in shape (Price and Kelly 1992).

Population densities can vary dramatically by habitat, season, and annual reproductive output (Bleich 1973, 1977, McClenaghan and Taylor 1993). Densities in good habitat typically are about 1-10 individuals per ha (O'Farrell and Uptain 1989) but can exceed 50 per ha in some areas during the spring and summer when juveniles are present (McClenaghan and Taylor 1993). O'Farrell and Uptain (1989) characterized low density as less than 4 SKR per ha, medium density as 4-8, and high as >8.

## 2.6. Reproduction

Breeding behavior of SKR is not well studied, but is probably similar to most kangaroo rats in being generally promiscuous. Reproductive output is relatively low for rodents of their size. SKR may be somewhat more productive than most kangaroo rats, due to the generally moister conditions in their geographic range, which can increase reproductive output and prolong the breeding season beyond what is possible in the arid desert habitats of most other kangaroo rat species. SKR generally produce two litters per year, with an average litter of two or three pups each. The peak of the breeding season is late winter and spring, but males may be reproductive throughout the year.

Reproduction is positively related to rainfall, but the pattern is complex. Breeding is stimulated by young, green vegetation. In years with higher than average rainfall, SKR may have an extended breeding season with more litters, and females may breed during their first year, rather than waiting until the second year, which is more typical. However, overly abundant rain, especially over consecutive years, may create dense vegetation that impedes SKR movements and may reduce reproductive output, although this also depends upon soil conditions and disturbance processes, such as grazing and fire which can reduce vegetation and thatch and increase bare soil exposure.

Young are born altricial and stop nursing by about 18 days old (at least in captivity). Juveniles are philopatric, remaining near their natal burrow for an extended period (Shier 2009). They typically establish home ranges centering about 30 m (100 feet) from their site of initial capture (Shier 2009). However, they are capable of moving and settling 400 m or more from their birthplace.

## 2.7. Communication

Like other medium to large kangaroo rats, SKR will drum with their hind feet as a form of long-distance communication. SKR drums at the fastest rate documented to date, averaging 24.44 beats per second (Shier et al. 2012). The low frequency sound may be masked by vibrations from automobile traffic, which may also confuse SKR and cause them to falsely respond by foot drumming to traffic noise, which may be energetically or behaviorally costly (Shier et al. 2012).

Sand- or dust-bathing is a mode of short-distance, social communication via scent, and is also used to remove excess oils and control external parasites. In SKR sandbathing appears also to be a means by which females communicate to males whether they are in estrus (Shier, unpublished data).

## 2.8. Activity Patterns

Like all kangaroo rats, SKR are nocturnal, generally emerging from their burrows shortly after dusk to forage, explore, sandbathe, and interact with other individuals. Most activity is concentrated in the early evening, but animals may be active at any hour during the night. SKR do not hibernate and are active above ground year-round, but time outside the burrow may be limited during cold or wet conditions. They also limit time outside during bright moonlight, presumably because light makes them more vulnerable to predation. Observations at the Ramona Airport suggest that animals are more active on cloudy nights around the full moon than on clear nights (W. Spencer, personal observations); and S. Montgomery (personal communication) has seen SKR concentrate activities in shady areas near shrubs on moonlit nights. Artificial lighting reduces the species' above-ground foraging activity up to at least 50 m from a flood light during the new moon, presumably due to perceived increase in predation exposure (Figure 3); (Shier et al. 2020).

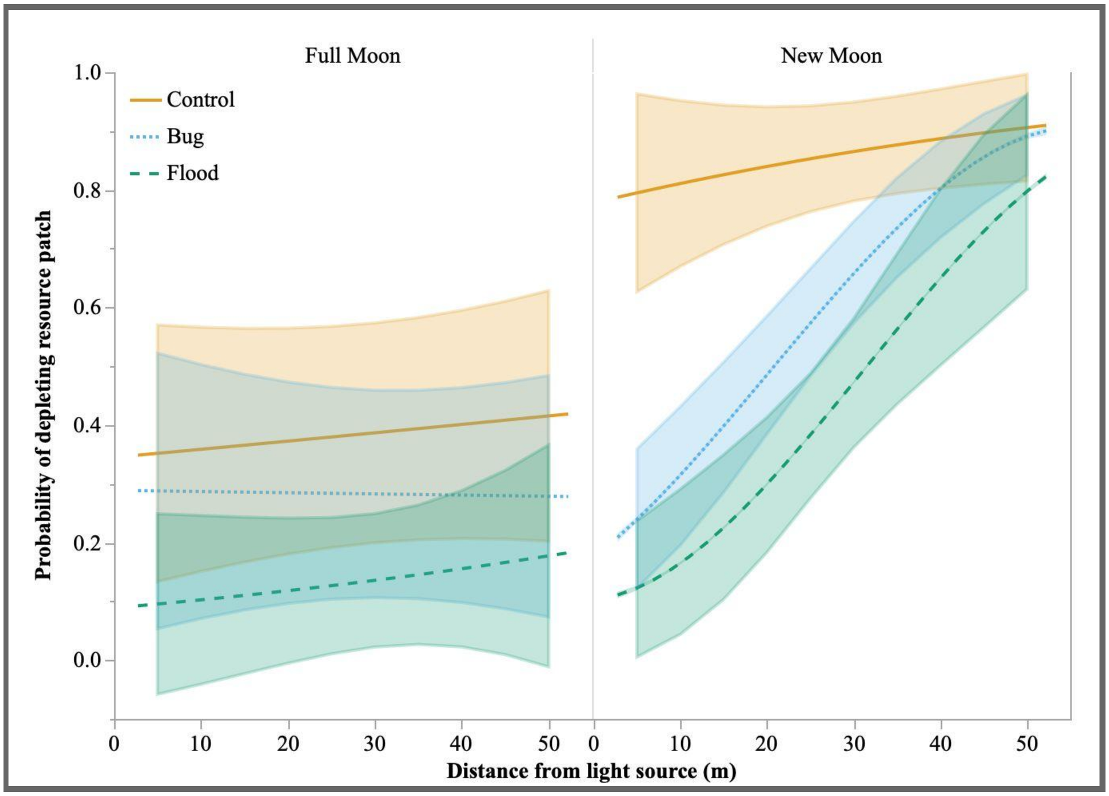


**Figure 3.** Probability of SKR depleting artificial seed patches as a function of distance from light sources during full moon and new moon nights. Reduced probability indicates reduced time spent foraging at patches (Shier et al. 2020).

## 2.9. Interspecific Relationships

Common predators of SKR include snakes (e.g., gopher snakes, rattlesnakes, and coachwhips), owls (e.g., barn and great horned), long-tailed weasels, and coyotes. Badgers may possibly also capture SKR in their burrows. House cats may be serious predators where residential development is adjacent to SKR habitat.

Kangaroo rats display an array of anti-predator behaviors, including reducing foraging on moonlit nights, foot drumming and kicking sand at snakes, plugging burrows from the inside to keep predators out, and ricochetal, zig-zag, bounding escape maneuvers. The prominent tuft at the tail tip of kangaroo rats is thought to attract a predator's eye and cause them to sometimes grab a tuft of hairs instead of the animal's body during attack; and the skin sheath of a kangaroo rat's tail can be readily pulled off when it is grabbed. When rattlesnakes strike at a kangaroo rat, the potential victim will reflexively leap high into the air and even vigorously kick the attacker to escape (see video documentation at Ninjarat.org). W. Spencer and D. Shier have observed foraging SKR suddenly disappear into burrows for at least an hour when barn owls fly overhead, although S. Montgomery (personal communication) has observed them to continue foraging after hearing owls overhead.

Kangaroo rats will readily take over burrows initially created by pocket gophers or ground squirrels, and they often cohabit burrow complexes with a variety of other rodents, lizards, or invertebrates. Because gophers and squirrels are stronger diggers than kangaroo rats, their burrowing can facilitate use of less friable soils by SKR.

The range of SKR overlaps with that of the more widespread Dulzura kangaroo rat (DKR; *Dipodomys simulans*; formerly considered Pacific kangaroo rat, *D. agilis*). Both species will occupy the open, forb-dominated habitats preferred by SKR, but DKR is generally more closely associated with coastal sage scrub habitat. Where both species occupy a local area, SKR may exclude the smaller DKR from open areas, restricting them to using shrubbier habitats. Bleich and Price (1995) studied interactions between the species in the laboratory and found that the larger SKR was more aggressive and competitively dominant over DKR. But, because SKR and DKR were housed in isolated enclosures which have been shown to increase aggression in other kangaroo rats (Yoerg, 1999), and they were tested in an extremely small arena, results of that study may not be biologically relevant. They suggested that SKR may force DKR out of their preferred open habitat, and that removing DKR from the system will not cause SKR to move into shrubbier habitats. The pattern of SKR in open habitats and DKR in adjacent shrub-dominated habitats can be observed on many SKR reserves. In areas where SKR are absent, DKR can be found using highly suitable SKR habitat (e.g., on Montecito Ranch in the Ramona Grasslands).

SKR also co-occur with a variety of other, smaller rodent species including San Diego pocket mice (*Chaetodipus fallax*), Los Angeles pocket mice (*Perognathus longimembris brevinasus*), deer mice (*Peromyscus maniculatus*) and cactus mice (*Peromyscus eremicus*). These species spatially segregate from one another, with each species utilizing slightly different microhabitat in terms of forb cover, shrub cover, and bare ground (Chock et al. in prep). The presence of SKR and DKR are associated with higher spatial segregation between species, likely driven by interspecific aggression and behavioral dominance of the larger kangaroo rats over smaller-bodied competitor species (Chock et al. 2018).

# 3. SKR Habitat Model

In 2019, in partnership with RCHCA, USFWS, and other SKR experts, CBI (2019) developed a fine-scale, rangewide habitat value model for SKR employing newly available Sentinel-2 satellite imagery (Appendix B: 2019 Stephens' Kangaroo Rat Habitat Suitability Model Final Report). A key advantage of this method is that the model can be updated on a regular basis and the resulting maps may be compared to one another and to the baseline conditions, providing for timely change detection. This provides a foundation for developing a comprehensive and consistent approach to SKR monitoring and management.

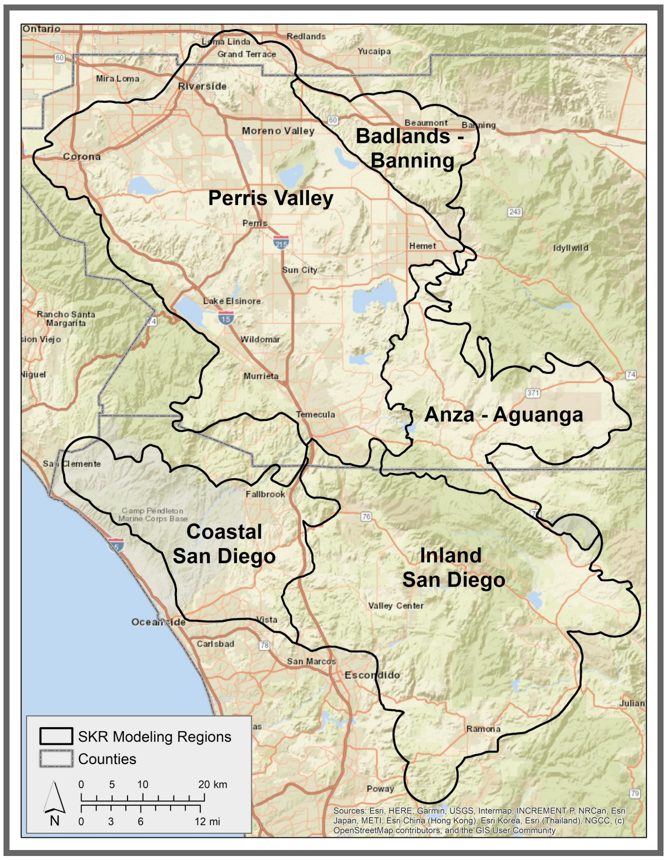


**Figure 4.** Subregions used for habitat modeling.

For this document, we improved on the 2019 rangewide map by dividing the SKR range into five modeling subregions (Figure 4) that reflect regional differences in climate and other habitat influences. By accounting for this regional variability, resulting models more accurately depict habitat quality within each subregion than the original, rangewide version. Stitching the five subregional maps together forms a single, rangewide habitat quality map that provides the best available assessment of SKR habitat distribution and quality as a foundation for planning and management.

The continuous range of habitat values produced by the model (from 0 to 1.0) can also be "thresholded" or "binned" into discrete categories, such as to differentiate suitable vs. unsuitable habitat or high, moderate, and low quality habitat.

## 3.1. Methods

Modeling was performed using Maxent methods (Phillips et al. 2006), SKR detection data from 1990-2018, and an array of environmental variables that characterize climate, terrain, vegetation, soils, and other habitat factors. In addition to traditional GIS variables, we developed an array of variables from multispectral satellite imagery that are indicators of vegetation and soil characteristics, such as vegetation greenness, wetness, and surface soil texture.

Modeling methods were the same as used for the 2019 rangewide model (Spencer and Romsos 2019), except that we mosaiced the results of five subregional models into a single rangewide map to better account for rangewide variation in climate and terrain. We initially based the subregions on an established ecological subsection map (Cleland et al. 2007), modified somewhat for SKR (by lumping and splitting) based on terrain and climate factors. Although the following regions (Figure 4) were defined solely to improve habitat modeling, regional differences may make these subdivisions useful for other planning purposes.

1. **Perris Valley**: This largest region includes the valleys and foothills between the Santa Ana and San Jacinto Mountains in western Riverside County. Considered the heart of the SKR range in terms of evolutionary history and genetic diversity, this hot, semi-arid region once supported widespread SKR habitat that is now highly fragmented by development and agriculture. A large number of isolated or semi-isolated SKR populations are broadly scattered throughout the region, many on reserve lands under an array of ownerships.

2. **Badlands - Banning**: This hot, arid region includes SKR habitat in the Badlands area between Moreno Valley and Beaumont and in the San Gorgonio Pass between the San Jacinto and San Bernardino Mountain Ranges. SKR are found on lands managed by CDFW (San Jacinto Wildlife Area) and BLM in this region, but the majority of habitat is on private lands.

3. **Anza - Aguanga**: This relatively arid inland region is in southern Riverside County, east of Vail Lake and Lake Skinner, where potential SKR habitat and known populations are scattered across wide, elevated plains between the San Jacinto, Palomar, and Cahuilla Mountains.

4. **Inland San Diego**: This hot, semi-arid region in north-central San Diego County has a complex topography of hills, mesas, and valleys. SKR populations are scattered in grassy valleys and basins which tend to be isolated by rocky hills and development. Substantial populations persist in the Santa Maria (or Ramona) Valley on a patchwork of preserved and private lands; the Warner Basin (or Lake Henshaw grasslands), where most SKR habitat is owned and managed by the Vista Irrigation District; and privately owned Rancho Guejito, northwest of Ramona. All three of these areas are grazed by cattle.

5. **Coastal San Diego**: This ecoregion on the coastal plains and hills of northwest San Diego County has cooler summers and a less arid climate than the rest of the SKR range. SKR are currently restricted to military lands here (Marine Corps Base Camp Pendleton and Fallbrook Naval Weapons Station) following intensive development in historic SKR habitat outside the military boundaries. Disturbance from military training, including frequent fire and ground

disturbance by vehicles and soldiers, are at least partly responsible for maintaining SKR habitat conditions, along with livestock grazing on Fallbrook Naval Weapons Station.

All potential environmental predictor variables were first evaluated separately using univariate Maxent models for their ability to predict SKR presence in each subregion at multiple spatial scales using moving-window averaging, from the finest available resolution (20 x 20 m; the resolution of input variables) up to a 60-$m^2$ radius circle (11,310 $m^2$ or 2.8 ac). Highly correlated variables ($r > |0.7|$) were competed against one another such that the one best predicting SKR presence was retained and weaker predictors removed. The resulting pool of independent variables was then entered into a single multivariate Maxent model, with each variable entered at its best performing scale from the univariate tests. The resulting multivariate model was then subjected to a systematic "pruning" and "tuning" process to create a more parsimonious model with the most appropriate parameter values. The only other difference from the previous (Spencer and Romsos 2019) model methods was that 80% of SKR localities were used for model training, with 20% withheld for model testing, in each subregion (as opposed to 70% training and 30% testing used in the single rangewide model.) See Appendix B: 2019 Stephens' Kangaroo Rat Habitat Suitability Model for more technical details about the methods for creating, tuning, and testing the model.

This modeling process was performed for each of the five subregions, and the subregional results were then stitched together using GIS into a single rangewide habitat quality, or value, map. The continuous habitat values (ranging from 0 to 1) can be interpreted as representing the likelihood or capability of an area to support SKR. We also thresholded this continuous likelihood output using the MAXSS criterion (Liu et al. 2013, 2016) into binary suitable-unsuitable categories for some purposes. This thresholding into suitable and unsuitable categories balances the potential errors of either over-predicting or under-predicting the likelihood that an area can support SKR, although some inaccuracies are inevitable given the probabilistic nature of habitat value models.

## 3.2. Results and Discussion

The rangewide habitat quality map produced by mosaicing the results of five subregional models provides a broad and consistent perspective of SKR habitat conditions across the entire planning area. This subregionalized map appears to more accurately capture nuances in habitat quality across the range, and especially at the scale of individual reserves or clusters of reserves, than any previous SKR habitat maps, including the 2019 rangewide model (Spencer and Romsos 2019). The new map provides the best available estimate of SKR habitat value across the range to serve as a foundation for conservation planning.

Table 1 summarizes the most important variables (as rated by MaxEnt permutation importance) for predicting SKR habitat value in each of the five subregions (Appendix C: 2020 SKR Habitat Suitability Model Predictors provides more details about the percent contribution and permutation importance of the variables in each model). A few variables were important in all or most areas and others were most important in specific subregions. For example, whereas terrain slope was an important predictor in all regions, light pollution and distance to non-perennial stream courses (i.e., ephemeral drainages or washes) were stronger predictors in the Badlands region than others; topsoil grain size was more important in the Perris Valley than others; and elevation was more important in the Anza-Aguanga region than others.

The resulting habitat quality map is consistent with, but more nuanced than, existing understanding and mapping of SKR habitat distribution, showing a few fairly large, contiguous habitat areas (e.g., Warner Basin, Rancho Guejito, Lake Mathews) but many smaller, more fragmented areas. The continuous habitat value map shows a wide range of habitat qualities even within occupied SKR areas. This can help managers target where habitat improvements may be possible within a reserve, and the effects of management actions on habitat quality can be tracked over time. The map also shows many habitat patches on unconserved, mostly private lands where surveys have not been performed.

The thresholded habitat suitability map (Figure 6) provides a simpler, dichotomous version that can be used for tracking the amount and distribution of suitable habitat in the SKR range (i.e., habitat with high enough value to be considered capable of supporting SKR). Note that alternative thresholds could also be set for different purposes. For example, a lower suitability threshold may be desired for regulatory purposes, such as showing where SKR presence-absence protocol trapping is warranted to conclude SKR absence for environmental assessments, or multiple thresholds can be set to delineate high, moderate, or low quality habitat areas.

**Table 1.** Variables in the habitat models for five modeling subregions ranked by permutation importance (see Appendix C: 2020 SKR Habitat Suitability Model Predictors for details).

| | |
|---|---|
| **Perris Valley** | |
| Topsoil Grain Size Index, September<br>Proportion Developed and Ag. Land Use<br>Slope<br>Normalized Difference Red Edge Index, April<br>Tasselled Cap Wetness, September<br>Distance to Primary/Secondary Roads | Distance to Non-Perennial Streams<br>Tasselled Cap Brightness, Apr/Sept Difference<br>Nightlight<br>Normalized Difference Texture Index, Apr/Sept Difference |
| **Badlands – Banning** | |
| Slope<br>Nightlight<br>Proportion in Developed and Agricultural Land Use | Average Precipitation, 1981-2010, March-May<br>Distance to Primary/Secondary Roads<br>Tasselled Cap Wetness, September |
| **Coastal San Diego** | |
| Slope<br>Tasselled Cap Wetness, September<br>Distance to Primary/Secondary Roads<br>Elevation<br>Modified Chlorophyll Absorption in Reflectance Index, Apr/Sept Difference | Proportion in Developed and Agricultural Land Use<br>Normalized Difference Sand Dune Index, Apr/Sept Difference<br>Anthocyanin Reflectance Index, April-Sept Difference<br>Alpha (measure related to mean soil pore diameter), 30-60cm |
| **Anza – Aguanga** | |
| Elevation<br>Slope<br>Distance to Non-Perennial Streams<br>Anthocyanin Reflectance Index, Apr/Sept Difference<br>Topsoil Grain Size Index, September<br>Clay Percentage, 0-5cm | Normalized Difference Sand Dune Index, Apr/Sept Diff.<br>Nightlight<br>Average Precipitation, 1981-2010, March-May<br>Normalized Difference Texture Index, Apr/Sept Difference |
| **Inland San Diego** | |
| Slope<br>Tasselled Cap Wetness, September<br>Modified Chlorophyll Absorption in Reflectance Index, Apr/Sept Difference<br>Normalized Difference Sand Dune Index, Apr/Sept Difference | Proportion in Developed and Agricultural Land Use<br>Distance to Primary/Secondary Roads<br>Normalized Difference Texture Index, Apr/Sept Difference |

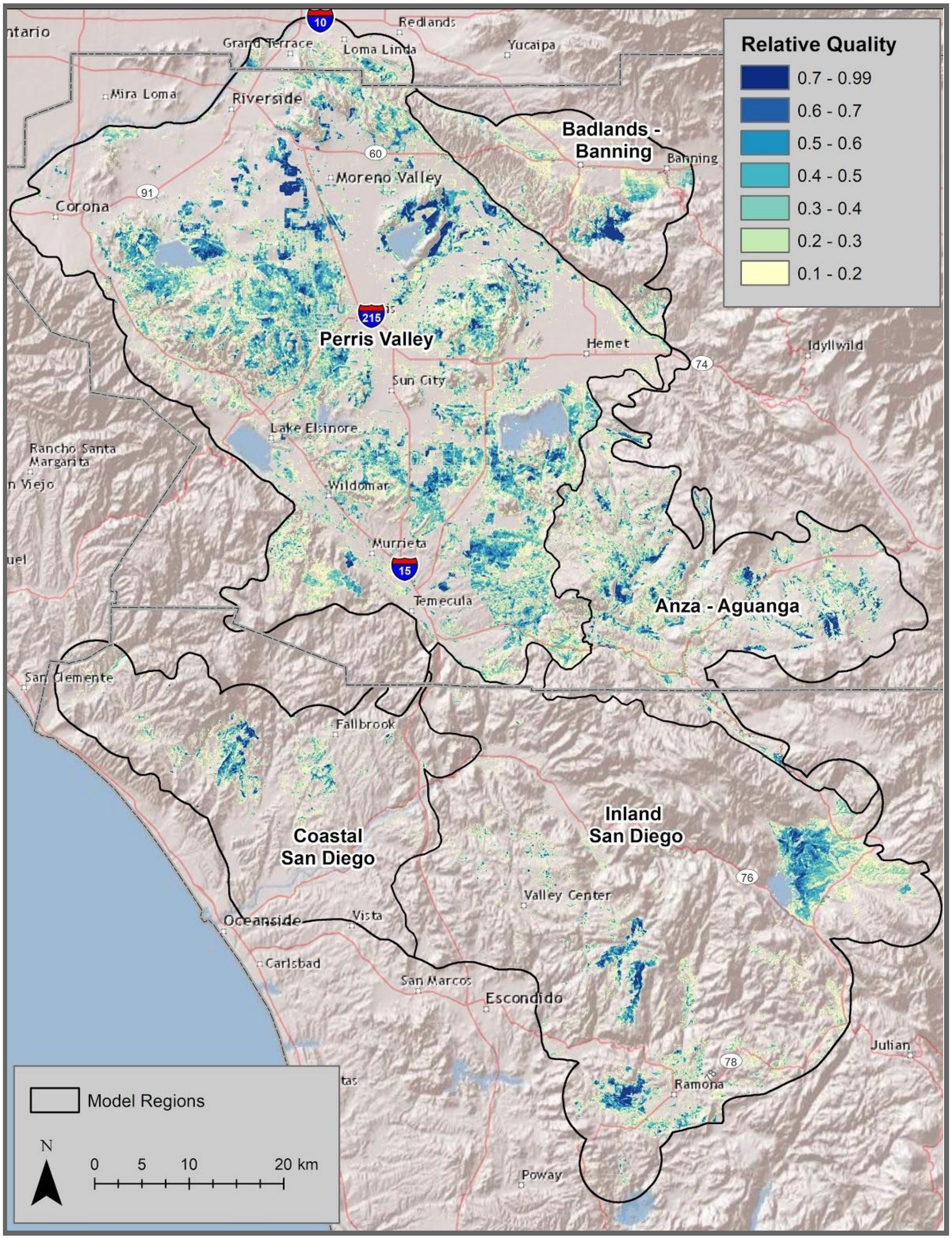


**Figure 5**. Rangewide SKR habitat quality created by mosaicing results of five subregional habitat models.

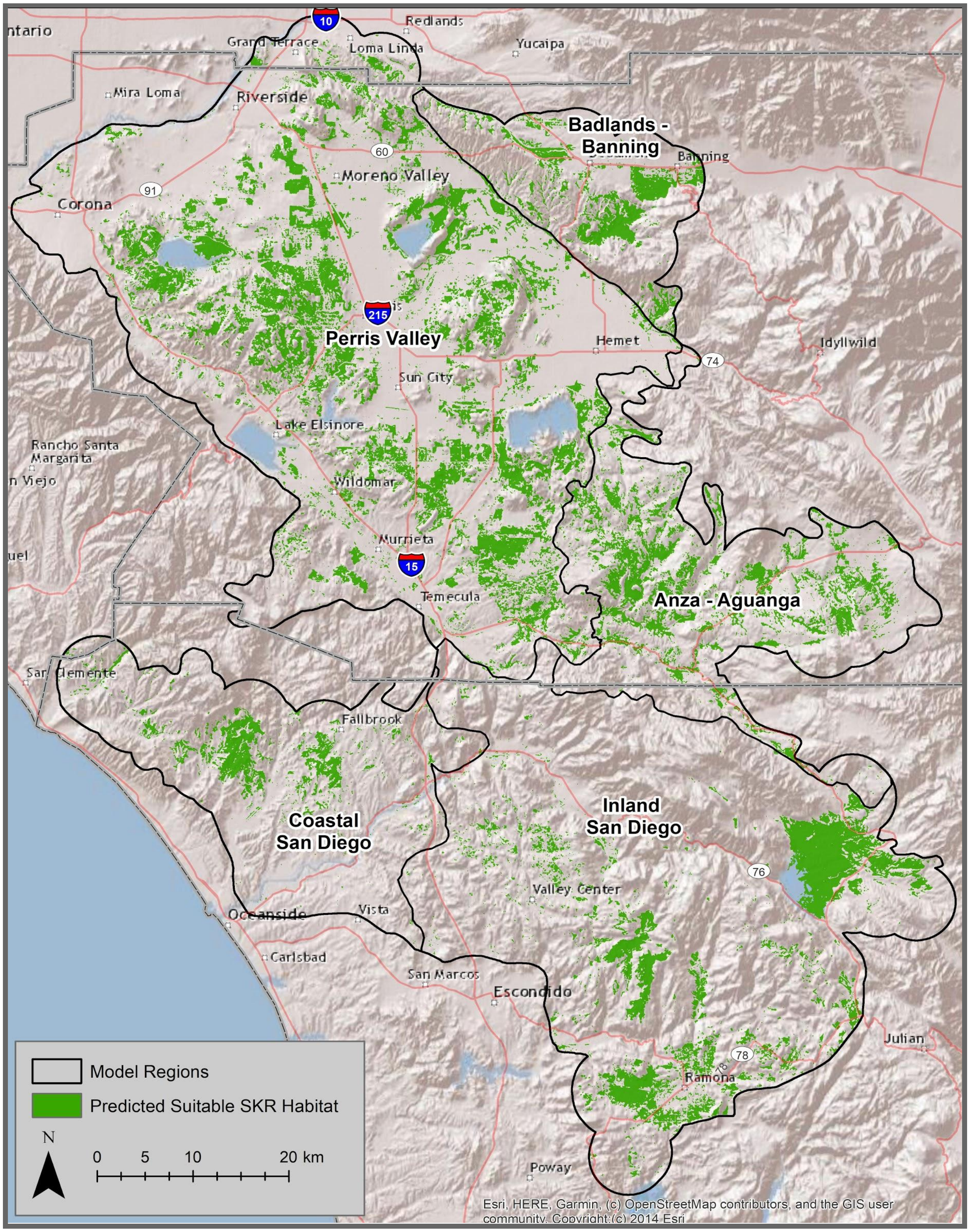


**Figure 6.** Modeled suitable SKR habitat produced by thresholding habitat values into suitable vs unsuitable habitat classes using the MAXSS criterion.

# 4. Delineating SKR Habitat & Population Units

For monitoring, it is necessary to delineate the spatial "**habitat units**" and "**population units**" within and among which sampling allocation will be distributed. However, because habitat value is spatially and temporally nuanced and complicated--with some large, contiguous habitat blocks but many smaller isolated or clustered patches--a replicable method for delineating biologically meaningful habitat units and subpopulations is needed. We therefore used SKR spatial ecology to define preliminary SKR habitat and population units, which should be refined with further analysis and expert discussion.

## 4.1. Methods

We used GIS to delineate draft SKR habitat and population units by considering the size and spatial contagion of habitat patches and the dispersal abilities of SKR. The intent was to define relatively discrete habitat areas for monitoring purposes, recognizing that suitable habitat may be fragmented at finer scales than SKR genetic, demographic, or movement patterns. Biologically, the units can be considered areas within which SKR may interbreed as a subpopulation, but with rare dispersal between independent units (e.g., units separated by long distances or dispersal barriers).

To delineate draft habitat units, we first removed suitable habitat patches (defined using MAXSS thresholding, as shown in Figure 4) < 1 ha in size. These are assumed to be too small to independently sustain SKR over multiple generations. We next used GIS to group suitable patches within 200 m (a relatively conservative dispersal distance) of one another on the assumption that clusters of habitat patches this close together could potentially support an interbreeding subpopulation with frequent movements among patches. Resulting clusters of habitat patches totalling < 50 ha (124 ac) were removed, assuming that 50 ha is large enough to potentially support a population of hundreds of SKR at carrying capacity (i.e., when the habitat is fully saturated by adult SKR) and is therefore sustainable for years to decades. The resulting habitat patch clusters > 50 ha were numbered as habitat units, treating units > 200 m apart as independent of one another (although they may be occasionally connected demographically by inter-unit dispersal).

The resulting habitat units were then intersected with SKR locality points (buffered by 160m to account for imprecision of localities in the SKR database) to designate which habitat units are known to have been occupied by SKR at least once during the period 1990-2018 (the temporal window represented by the SKR locality database). Unlike the fine-scale filtering of SKR localities used for creating the habitat model (points with >320m precision were omitted during model creation), for determining unit occupancy we relaxed the locality precision criterion, which proved overly restrictive in identifying which habitat units were occupied by SKR (e.g., some definitive localities within large habitat units had >320-m but <0.5-mile precision). Habitat units with no definitive SKR observations may be considered unoccupied, or more accurately, as having unconfirmed occupancy since 1990.

This initial draft of habitat units should be refined early in Plan implementation by at least (1) updating the SKR locality database (to account for areas known to support SKR but lacking database localities, or populations known to have been extirpated in recent years) and (2) splitting some units where there are obvious SKR dispersal barriers (e.g., major roads or canals) crossing them. In addition, we recommend (3) evaluating alternative habitat value thresholds for delineating the units for monitoring or other purposes--for example to define units having occupancy rates that balance the statistical power and efficiency of the sampling design (W. Miller, personal communication; see Section 8.3. Occupancy Monitoring). The resulting population units can then serve as the spatial sampling units for monitoring by PAO occupancy estimates (MacKenzie et al. 2002) and the results can be used to track SKR occupancy and trends, and perhaps overall population size. In addition, population units could be used in a dynamic metapopulation model (Hanski 1999, Schumaker and Brookes 2018) to assess population dynamics and different management scenarios for increasing population health and viability.

## 4.2. Results

The clustering procedure yielded 118 draft habitat units totaling, 77,849 ha (192,369 ac) (Figure 7). Of these, 39 are mapped as potentially occupied, totaling 64,192 ha (158,622 ac) (Figure 8) and therefore assumed to be population units. Both habitat units and population units vary from 54 to 10,136 ha each, but with a mean area of 660 ha for all habitat units and 1,646 ha for occupied habitat (or population) units. As expected, the larger average size of occupied (versus occupancy unconfirmed) habitat units suggests that larger habitat areas are more likely to be occupied, although they are also more adequately sampled for SKR presence. *Note that these draft units must be reviewed and refined before use, as described below.*

The distribution and extent of population units generally corresponds with known SKR population areas, although they surely overestimate the actual areal extent of SKR occupancy due to the naturally patchy and dynamic nature of SKR occupancy within suitable habitat areas and fine-scale habitat fragmentation and edge effects in many areas (e.g., in the central Perris Valley around Steele Peak). Note also that occupancy patterns fluctuate over time due to SKR population dynamics (e.g., with local patches becoming colonized or extirpated over time) such that suitable habitat polygons will rarely be fully occupied by SKR at any time. *These factors should be further investigated and refined using statistical occupancy estimates (MacKenzie and Reardon 2013) during early Plan implementation as a better index of species status and trends. In addition, these draft units should be refined by, for example, splitting units where there are obvious SKR dispersal barriers such as major highways crossing them and by evaluating alternative habitat value thresholds to maximize sampling efficiency. Preliminary expert review suggests the units may be overly inclusive for monitoring purposes as currently delineated using the MAXSS thresholding criterion.*

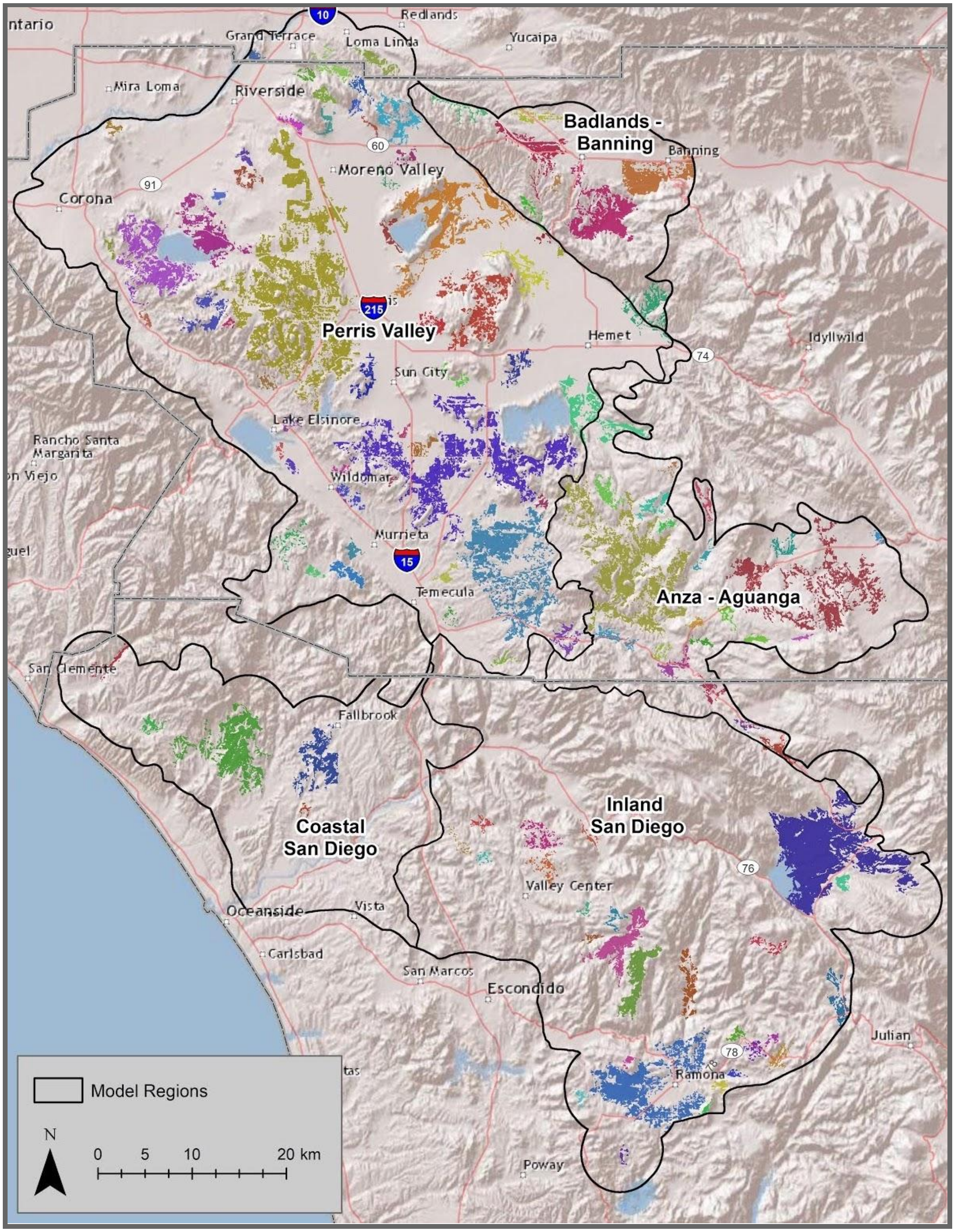


**Figure 7.** Draft SKR habitat units. Each color indicates a unit comprising patches of modeled suitable habitat within 200 m of each other, with different colors representing different units (> 200 m apart).

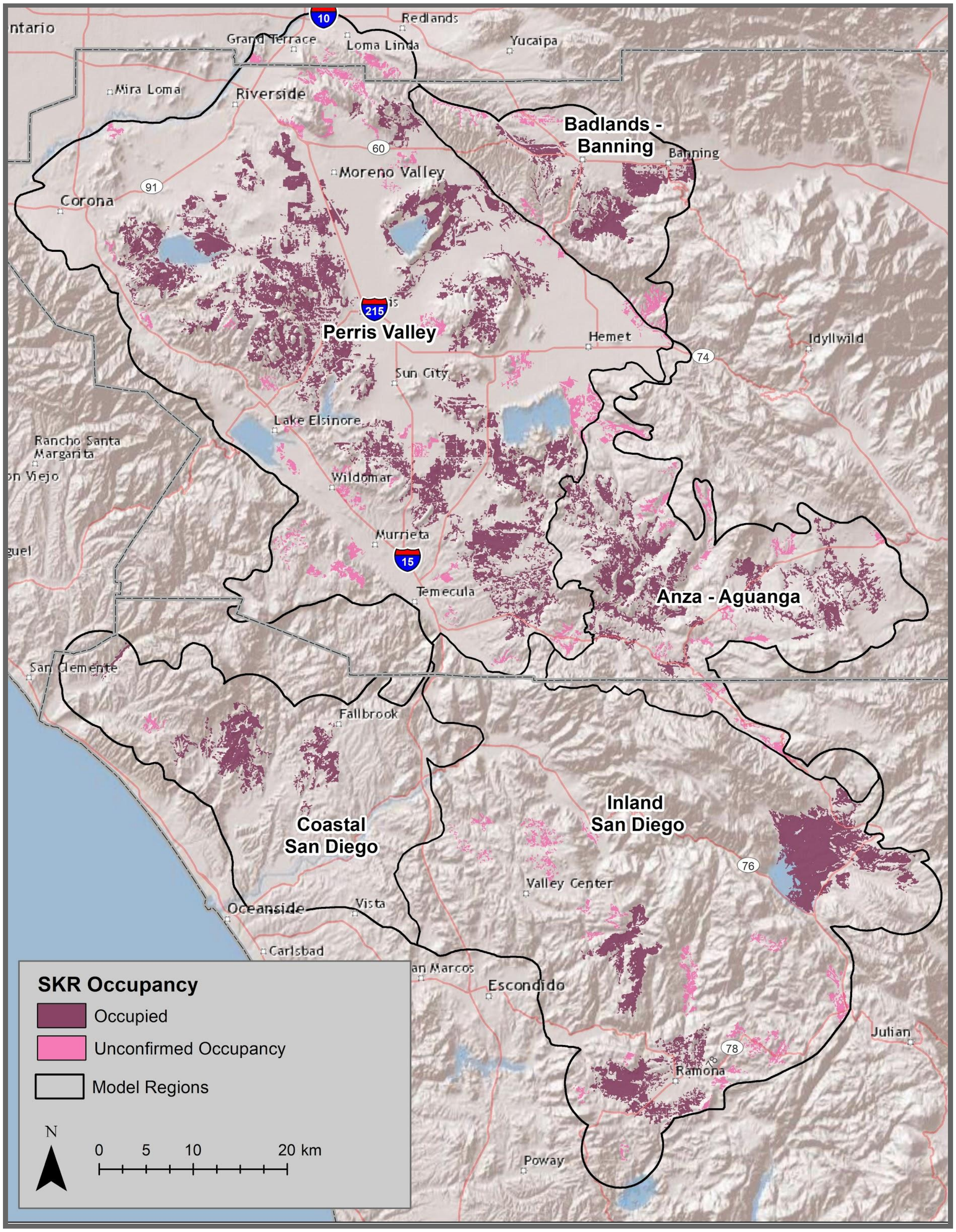


**Figure 8**. Draft SKR habitat units identified as potentially occupied (≥ 1 SKR observation) or unconfirmed occupancy (no SKR observations in the database). Occupied units are termed population units. Note that SKR may only occur in a portion of a unit and will rarely occupy entire units.

# 5. Biogeographic Working Map

Understanding the biogeography of SKR is essential to an effective, rangewide strategy for management and monitoring. The species' distribution is highly fragmented by human development and agriculture, with remaining habitat areas widely scattered across a landscape that varies substantially in climate conditions, land ownerships, management mandates, and other factors. Overlaid on this already complex conservation landscape are patterns of SKR genetic diversity that reflect both deep evolutionary changes as well as the effects of more recent, human-induced population fragmentation. These considerations can be spatially integrated into an SKR Biogeography Working Map (Figure 9), which uses the SKR habitat suitability layer as a foundation. The working map, or perhaps multiple maps, can be updated, refined, and used by Working Group members or others for planning, monitoring, or other purposes.

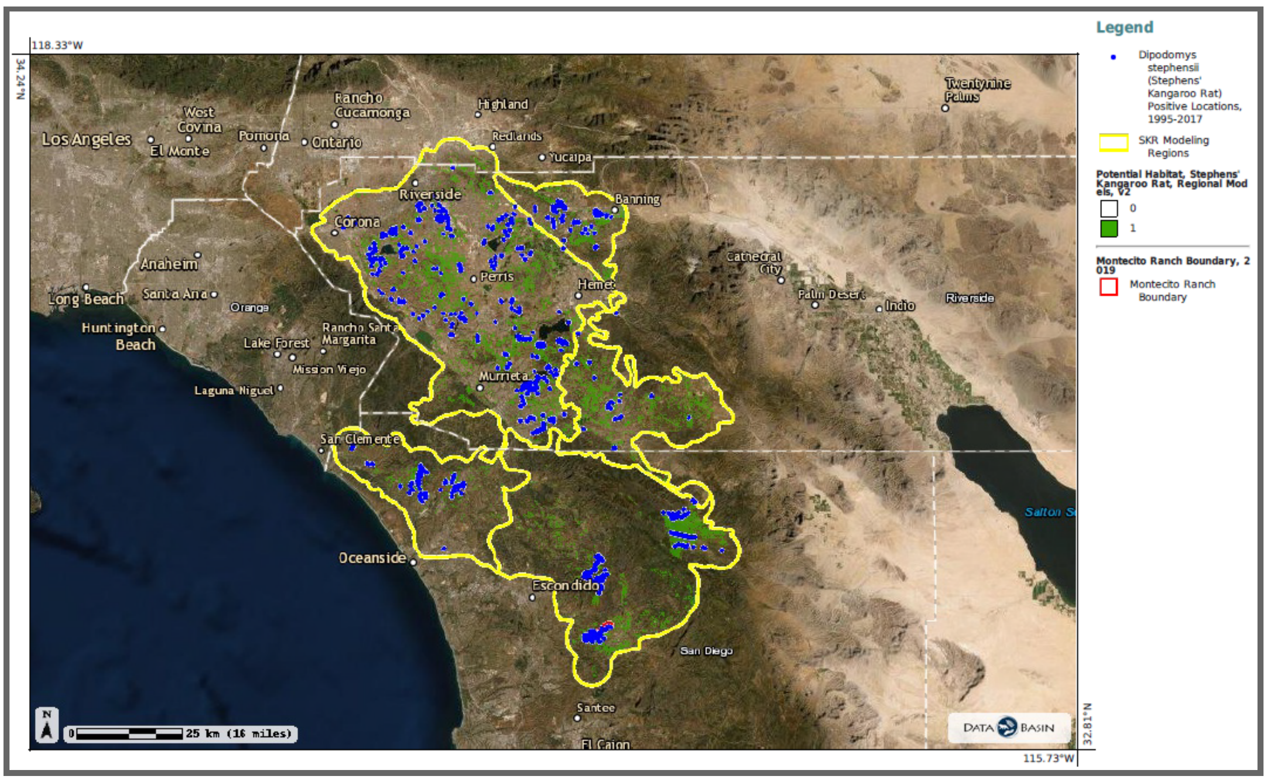


**Figure 9.** Illustration of SKR biogeography working map on Databasin.org. The live SKR Biogeography Working Map is available to SKR Working Group members for viewing, commenting on, updating, or downloading the data.

The biogeographic map and associated information reveals important regional patterns in SKR distribution and environmental conditions across the species' range:

- The large Perris Valley ecoregion supports many mostly small and fragmented SKR populations between the Santa Ana and San Jacinto mountain ranges. It has the highest genetic diversity in the range, but this diversity is threatened by the large degree of recent fragmentation by human development. Many of the remaining populations here are conserved, but improving inter-population connectivity is a high priority. A large proportion of acreage mapped as occupied (i.e., population units) may not actually be fully occupied due to extensive fragmentation and edge effects, for example, numerous vacant lots in suburban areas west of Perris and east of Temecula.

- East of the Perris Valley, SKR populations in the Badlands - Banning subregion are mostly on private lands, with the exception of a relatively large contiguous population in the Potrero area, which is largely conserved.
- The Anza - Aguanga subregion supports scattered SKR populations at generally higher and drier elevations than other areas, mostly on private and tribal lands. SKR have not been as extensively monitored or studied in this subregion as others, in part due to land access constraints, and SKR occupancy may be poorly documented.
- In north coastal San Diego County, SKR are currently restricted to military lands (Marine Corps Base Camp Pendlenton and adjacent Fallbrook Naval Weapons Station) due to extensive development that extirpated SKR outside of military boundaries. SKR in this subregion experience generally moister, cooler conditions than in other areas. They have been well monitored here relative to other areas, and much effort has been put into developing and refining monitoring approaches and protocols on the military lands. SKR population distribution is well documented here and is sparse and fragmented.
- In more inland San Diego County, SKR are mostly restricted to three relatively large and intact areas, one of which (Ramona Grasslands) is mostly conserved, whereas the two others (Rancho Guejito and Lake Henshaw/Warner Basin) are not. All three populations are on lands grazed by cattle for many years. Outside of these three areas, habitat is highly fragmented on mostly private lands, where survey efforts have been relatively sparse and potential population distribution not fully documented.

The following section provides more details about land ownership and SKR management status on each of these major regional subdivisions.

## 5.1. Known SKR Populations and Reserves

Many SKR habitat and population areas have generally accepted place names, including formal reserve names as well as informal geographic descriptors. This section presents place designations used in this document and on associated maps for clarity. The place names are organized by subregions with some brief notes concerning alternative names, ownership, management, or setting. *This list is incomplete, and we recommend it be updated and refined during Plan implementation to ensure that all potentially important SKR habitat areas, whether conserved or not, are considered and accurately portrayed on maps.*

**Perris Valley**: The valleys and foothills between the Santa Ana and San Jacinto Mountains in western Riverside County have numerous highly fragmented SKR habitat areas, including about a dozen different reserves under an array of ownerships. This region includes most of the RCHCA SKR reserves.

- RCHCA Core Reserves (note: Core Reserves have designated boundaries within which there is often a patchwork of conserved and nonconserved lands):
  - Lake Mathews / Estelle Mountain Reserve -- This large reserve area has a complex ownership pattern with lands owned by RCHCA, BLM, Metropolitan Water District, Riverside County Waste Resources, and CDFW.
  - Sycamore Canyon Reserve -- Includes land owned by City of Riverside and CDFW (Sycamore Canyon Ecological Reserve) near the City of Moreno Valley. Also referred to as Sycamore Canyon Wilderness Park.
  - Steele Peak Reserve -- This reserve consists of several disjointed parcels owned by RCHCA and BLM west of the City of Perris.
  - Motte / Rimrock Reserve -- This is a UC Riverside Reserve partly owned and managed by BLM northwest of the City of Perris.
  - San Jacinto / Lake Perris Reserve -- This large reserve comprises CDFW and California State Park lands as well as some CDFW conservation easements on private lands.
  - Southwestern Riverside County Multi-Species Reserve -- This large reserve around Lake Skinner and Diamond Valley Lake has a complex ownership pattern, including lands owned by RCHCA, BLM, CDFW, Metropolitan Water District, Riverside County Regional Park and Open Space District, and private easements and mitigation bank parcels. It is sometimes referred to as the Lake Skinner / Domenigoni Valley Reserve.

  We currently have little or no information on the following reserves, which should be rectified early in Plan implementation:
  - Triple Creeks Conservation Area / Box Springs Preserve Park
  - Alberhill Conservation Area
  - Harford Springs Reserve southeast of Lake Mathews
  - North Peak Preserve, Lake Elsinore

- March Air Reserve Base -- About 660 acres of former military land, now owned by the March Joint Powers Authority, was set aside as a permanent reserve for SKR and other wildlife in 2012. It is managed by the Riverside Land Trust, but apparently is not managed nor regularly monitored for SKR. A reconnaissance and trapping survey was conducted on the base and nearby lands during 2019, documenting no SKR on the base east of I-215 but widespread and "abundant" SKR on lands west of I-215 (ECORP Consulting, Inc. 2020); however, it is unclear whether this includes the 660 acres managed by Riverside Land Trust.

- Kabian Park -- This 640-ac park near Quail Valley is managed by the Riverside County Regional Park District. It is nearly all undeveloped natural habitats, including predicted suitable SKR habitat. Although it is unknown if SKR are present, SKR were recorded on nearby properties during the early 1990s.

**Badlands - Banning**: This region supports SKR habitat in the Badlands area between Moreno Valley and Beaumont and in the San Gorgonio Pass between the San Jacinto and San Bernardino Mountain Ranges. SKR are found on lands managed by CDFW (San Jacinto Wildlife Area) and BLM (Potrero

ACEC) in this region, but much of the occupied habitat is on private lands in and near the cities of Beaumont and Banning.

- Potrero Reserve (an RCHCA Core Reserve Area) -- This large reserve area comprises CDFW and BLM lands partly outside of the Riverside County SKR Plan Area. It includes the San Jacinto Wildlife Area (CDFW) and adjacent parcels in the BLM's Potrero ACEC (Area of Critical Environmental Concern). The Potrero Creek portion of the San Jacinto Wildlife Area consists of approximately 2000 acres of occupied SKR habitat, primarily in level and gently sloping valley bottoms and larger adjacent rounded ridgelines. The property contains areas currently under study for contaminants deriving from early rocket testing activities. (Note that the ACEC parcels are incorrectly omitted from the Potrero Reserve on some maps and in some protected area databases, which instead map them as scattered parcels west of the Potrero Reserve that lack substantial SKR potential.)

**Anza - Aguanga:** This relatively arid inland region is in southern Riverside County, east of Vail Lake and Lake Skinner, where potential SKR habitat is scattered across wide, elevated plains between the San Jacinto, Palomar, and Cahuilla Mountains. Most SKR habitat and occupancy is on unconserved, private lands and the Cahuilla Tribal Reservation. BLM owns some small, scattered reserve lands, and there is at least one private conservation easement on a property with an SKR observation:

- Jalem Productions Acquisition -- This 1,156-ac parcel is a conservation easement owned by the Western Riverside Resource Conservation District (RCA). It supports a small amount of SKR habitat and has one SKR locality recorded in 2008, but it is unknown whether it is managed or monitored for SKR.

**Inland San Diego:** This hot, semi-arid region in north-central San Diego County has a complex topography of hills, mesas, and valleys. SKR populations are scattered in grassy valleys and basins which tend to be isolated by rocky hills and development. Substantial populations persist in the Santa Maria (or Ramona) Valley on a patchwork of preserved and private lands; the Warner Basin (or Lake Henshaw grasslands, which are mostly owned and managed by the Vista Irrigation District); and privately owned Rancho Guejito, northwest of Ramona and east of Escondido.

- Lake Henshaw / Warner Grasslands -- This large (perhaps the largest remaining) habitat area occupied by SKR is mostly owned and managed by the Vista Irrigation District for cattle ranching surrounding their Lake Henshaw reservoir, with some lands managed for SKR on Naval Base Coronado Remote Training Site Warner Springs under an Integrated Natural Resource Management Plan. The SKR population varies in density in both space and time in relation to intensity of cattle grazing (S. Montgomery, personal communication).

- Ramona Grasslands Reserve -- This reserve in the Santa Maria Valley has a patchwork of ownerships including County of San Diego Department of Parks and Recreation, San Diego Habitat Conservancy, and Ramona Municipal Water District (RMWD). Recent reserve additions are not yet included on reserve maps.

- Montecito Ranch -- Recently acquired by the Endangered Habitats Conservancy, this previously private ranch land adjacent to the Ramona Grasslands Preserve was found to support a sparse population of SKR in 1998 (Behrends 1998) but subsequent surveys found only Dulzura kangaroo rat (DKR; *Dipodomys simulans*) on the property following discing, changes in grazing management, and perhaps rodenticide poisoning (REC Consultants, Inc. 2008, Montgomery 2019, Ogilvie 2020). A Habitat Management Plan is currently in preparation by CBI, which is considering habitat improvements and possibly an attempt to re-establish SKR there.

- Rancho Guejito -- This large private ranch is owned by The Rodney Company, a New York based real estate company. This last remaining Spanish land grant parcel in San Diego County has long been managed for cattle grazing. Since 2004, the owners have pursued major development plans and expansions of agricultural practices on the property, and showed no interest in selling for conservation purposes, but current plans are unknown. S. Montgomery discovered SKR on the ranch in 1991 and trapped for SKR in 1991 and 2004, mapping over 1200 ha of occupied habitat in 2004 across two large grassland areas separated by slopes of oak woodland and chaparral.

- Paradise Valley Preserve -- This is a recent acquisition by the County of San Diego as an addition to the Hellhole Canyon Reserve. This small area on the boundary of Rancho Guejito supports a portion of that large SKR population.

- Santa Ysabel Grasslands -- SKR have not been confirmed present in this area at the eastern edge of the species' range, although it is hypothesized that they must have occurred here in the past (Spencer 2002). In 2000, W. Spencer observed a kangaroo rat burrow and scat in high-quality SKR habitat in what later was conserved as the Santa Ysabel Open Space Reserve. However, in 2001, W. Spencer and S. Montgomery were unable to find any kangaroo rat sign during intensive reconnaissance of the reserve lands, and noted a nearly total lack of *any* rodent sign in the Santa Ysabel grasslands. Spencer (2002) surmised that SKR must surely have occurred there in the past, as they represent the most significant potential "stepping stone" habitat patch between the nearby Lake Henshaw and Ramona populations. He concluded that the Henshaw and Ramona populations were probably genetically linked via this stepping stone area, which could well be occupied by SKR again in the future provided that SKR dispersal potential was maintained between these three SKR habitat areas.

**Coastal San Diego** -- This ecoregion on the coastal plains and hills of northwest San Diego County has cooler summers and a less arid climate than the rest of the SKR range. SKR are currently restricted to military lands here (Marine Corps Base Camp Pendleton and Fallbrook Naval Weapons Station) following intensive development in historic SKR habitat outside the military boundaries. SKR on these military installations are managed under two Integrated Natural Resources Management Plans (INRMP; one for Camp Pendleton and one for Fallbrook Naval Weapons Station).

## 5.2. Metapopulation Structure

As mentioned above, SKR are currently distributed as a large, complex metapopulation--or more likely a number of regional metapopulations with little if any gene flow between them. For example, it is likely that the coastal San Diego SKR populations on Camp Pendleton and Fallbrook Naval Weapons Station function as one metapopulation that is isolated from all other populations. In inland San Diego County, there could be one to several metapopulations, given uncertainties about the potential for dispersal between the Rancho Guetijo, Ramona, and Warner Basin habitat areas, or between Warner Basin and populations in the Anza - Aguanga region. The situation in Perris Valley and the Badlands region is complex and highly uncertain due to the large number of scattered population areas and little information on likely dispersal patterns that would allow for gene flow amongst them.

## 5.3. Population Genetic Considerations

Spatial and temporal patterns in genetic diversity (**genetic structure**) are important to consider in a rangewide management plan to help maintain sufficient **genetic diversity** to ensure that the species can **adapt** in response to selective pressures. Recent genetic analyses using **microsatellite markers** (Shier and Navarro 2016) suggest there may be 15 **genetic clusters** represented within the SKR's geographic range. Two clusters are relatively distinct (with the Ramona Grasslands and Rancho Guejito grouping as one cluster, and Lake Perris and adjacent San Jacinto Wildlife Area as another). However, by another genetic metric, **Fst values**, the Ramona and Guejito populations are clearly separable, suggesting that dispersal between them is likely rare or nonexistent. Other clusters are less discretely separable than these two, with a fair degree of shared genes amongst sites. This suggests that there has been a relatively high degree of genetic mixing amongst SKR populations at least in the past, even if there has been a reduction in gene flow more recently due to habitat fragmentation by humans.

Overall, SKR genetic diversity, as measured by observed **heterozygosity** and **allelic richness**, is relatively high, especially in light of the amount of habitat fragmentation that currently exists. Diversity is highest in the north-central part of the range in Riverside County and lowest in southern populations. The results suggest that SKR evolved in the northern portion of the current range with relatively high genetic mixing, and then expanded southward, losing local diversity in the expansion areas. There is an associated **isolation by distance** effect, in which those populations that are farthest apart differ more genetically from one another than do populations closer together (Shier and Navarro 2016).

The lowest diversity occurs in the relatively isolated, southernmost populations (Ramona Grasslands, Rancho Guejito, and Camp Pendleton/Fallbrook Naval Weapons Station). The Ramona Grasslands population has the lowest genetic diversity, as well as the greatest differentiation from other populations as measured by **Fst values**. Although the Ramona Grasslands subpopulation clusters with the nearby Rancho Guejito subpopulation (perhaps suggesting they were once connected, or that both subpopulations derived from a common source population) there are nevertheless genetic differences between these two subpopulations as measured by Fst. These two subpopulations are separated by the very steep Santa Ysabel Creek Valley and associated chaparral and woodland vegetation, which probably act as a strong dispersal filter if not a complete barrier to SKR. This hypothesis deserves further genetic investigation.

In addition to the low genetic diversity and apparent isolation of the Ramona Grasslands subpopulation, existing genetic data indicate that it also has the lowest effective population size of all populations studied (Shier and Navarro 2016), suggesting it deserves consideration for a potential population intervention, perhaps including translocations from other sites to augment genetic health. However, the potential for local genetic adaptation in this location should also be considered: We do not know to what degree the gene pool of the Ramona population, or any other population for that matter, reflects **genetic drift** versus local **adaptation**.

# 6. SKR Threats Assessment

This Plan refines and updates information on threats to SKR using a threats assessment survey completed by land managers across a number of SKR reserves. This information helps validate and augment our existing understanding of rangewide threats to SKR with more refined information at the scale of individual reserves. Summarizing the reserve-level threats across the species' range provides further insights about regional and rangewide management priorities to help recover the species.

## 6.1. Methods

The SKR Working Group asked SKR reserve managers to answer survey questions about a list of potential threats to SKR and their habitat, including whether the threat occurred on land they manage, how likely it is to occur in the future, and the severity and spatial and temporal scales of the threat's impact to individual SKR or across the entire population on a reserve. They were also asked whether they were already managing for the threat, the resources being used to address it, and any constraints to managing the threat.

## 6.2. Results and Management Implications

Eight completed surveys were received for the following management areas: Marine Corps Base Camp Pendleton, El Sobrante Landfill, Lake Mathews, Montecito Ranch, Motte Rimrock Reserve, Naval Weapons Station Seal Beach Detachment Fallbrook, Southwest Riverside County Multi-species Reserve, and Naval Base Coronado Remote Training Site Warner Springs. The survey responses contain a wealth of information on reserve-level threats and management limitations, particularly in the detailed notes provided by reserve managers (see Appendix D: SKR Threats Survey Summary for a summary of key results, which are more briefly summarized here).

Overall, it is clear that habitat threats, especially invasive plant species and associated thatch buildup, are a rangewide concern, but that constraints to management, including available funding, staff time, and management tools, are limiting some managers' abilities to counter them. Invasive species was the top-ranked threat both in terms of frequency and management priority at all eight reserves, and invasive species were considered a severe threat to individual SKR (due to direct mortality of reductions in fitness) at six reserves and to the entire resident population at five of them. Thatch development, which is associated with invasive plant species, was similarly rated as both present and a top management priority at nearly all reserves.

Direct habitat removal and associated habitat fragmentation by development and infrastructure was the second-most frequent threat, and considered a top management priority if it were to occur, but it was generally considered unlikely to occur or to have impacts over large portions of a reserve. Direct habitat removal was reported as a top management priority at seven of the eight reserves due to its *potential* to have severe impacts, but it is generally unlikely to occur on biological reserves, or the extent can be minimized.

Small SKR population size and population isolation were also rated both present and a high management priority at most reserves for obvious reasons. Small population size acts as a threat because it reinforces the effects of biotic and abiotic processes that drive a population downwards toward extirpation. Habitat fragmentation by human development and agriculture, which limits SKR to scattered, often isolated reserve areas, puts them at risk of inbreeding depression, local extirpation due to stochastic events, and loss of adaptive potential over the long term. A primary goal of this rangewide SKR Plan is to reduce and mitigate these threats by increasing population size and connectivity to the degree feasible.

Some threats were identified at only a few reserves, but may be severe where they do occur. For example, predation by free-roaming cats, potential for excess water or soil moisture, tree and shrub encroachment, and light pollution were all listed at one or a few reserves each, with varying degrees of spatial distribution and severity. Light pollution was not considered a top priority at most reserves, but it was listed as among the top priorities at the Fallbrook Naval Weapons Station where it could potentially have significant impacts to SKR in a small proportion of available habitat were it not being addressed.

Severe and prolonged drought was listed as a threat to whole populations or significant portions of populations at five reserves, and soil moisture due to severe or prolonged rains at two reserves. Although SKR are generally well adapted to historical wet-dry weather cycles, the deeper and longer periods of drought and heavy rainfall that may occur due to climate change could have significant negative effects on SKR populations. For example, deep, multi-year droughts could deplete the seed sources needed by SKR, whereas heavy and prolonged wet cycles could flood or saturate soils to the point where SKR cannot survive due to damp burrows, hypothermia, and spoiled seed stores. Prolonged wet periods can lead to excessive herbaceous growth and thatch that reduce habitat value.

Habitat loss or decreases in quality due to changes in agricultural practices (e.g., grazing practices, vegetation management, irrigation) was considered both present and a management priority at four reserves, but only considered a severe threat to SKR at Montecito Ranch. This rating reflects changes in agricultural practices that occured on the Ranch prior to its conservation (discing, changes in cattle density, and perhaps rodenticide use) which may have extirpated SKR, as well as uncertainties about future practices until an approved habitat management plan is implemented.

Management capacity and constraints also emerged as high concerns at many reserves, especially funding and time limitations. “Available time or priority” were highly ranked as threats to SKR by six of the eight reserves and as top priority at three of them. Two respondents indicated that they were making efforts to address management limitations by prioritizing SKR management over other reserve goals, but that staff and time remained limiting factors. Limitations due to agency constraints, including having sufficient funding for management and access to appropriate management tools, were rated as high priorities at five of the reserves.

The survey revealed that although there are common issues across most or all reserves, each reserve has a unique combination of threats and management issues that need to be addressed. The land management plan of each reserve area should consider these combinations of real and potential threats and how they may interact to affect SKR fitness and population viability. Although managers should obviously address the highest priority threats, they should not lose sight of the potential for synergistic effects of multiple threats. For example, soils heavier in clay content are both more likely to accumulate thatch and to hold moisture for longer durations than better-drained, loamy soils; and even a slight increase in domestic animal predation, roadkill, or other direct mortality factors can have strong implications for already small or inbred populations.

# 7. SKR Management Strategy

The SKR Management Strategy summarizes methods for managing SKR habitat, populations, and threats, and provides guidance for strategically planning where and when these tools might best contribute to rangewide SKR conservation goals. Rather than reinventing wheels, this Plan builds on lessons learned from existing management plans, which are already being implemented on many reserves (Table 2). It summarizes successful techniques from these plans and offers guidance for improving management where needed, including for SKR management on areas not yet covered by SKR management plans (new or future reserves).

Perhaps most important, this Plan provides guidance for improving collaboration amongst the numerous agencies having SKR management responsibilities to better achieve rangewide conservation goals. Some management actions, such as species translocations and reintroductions, require coordination between multiple land owners and agencies, and management decisions with implications beyond a single ownership or reserve should be made by the SKR Implementation Team (see Chapter 11. Recommendations). In addition, some managers lack sufficient resources to perform certain tasks, and increased collaboration could help overcome such limitations by sharing information, staff time, funding, equipment, or other resources.

Appropriate management tools should be selected and applied in full recognition that reserve managers must achieve diverse resource management obligations that vary with land jurisdictions, ownership, and resource goals. Many reserves are not managed solely to benefit SKR; military lands managed to benefit SKR are not technically reserves and are managed under specific federal mandates; and some reserves are divided under multiple ownerships having differing mandates, resources, and constraints.

## 7.1. Deciding Where to Manage

Deciding when, where, and how best to manage SKR habitat, populations, and threats can happen at multiple scales by different people or teams, as briefly outlined here.

### 7.1.1. Reserve Level

Decisions about which management tools should be used where and when within an individual reserve are best made by the reserve manager who knows and understands the land, its history, and the resources the reserve has available. Of course, the manager should consult as needed with members of the SKR Technical Team if they have any questions about the best tools, techniques, timing, and locations to apply management. Managers should be fully aware that they can rely on the broad expertise of the SKR Technical and Implementation Teams, which may also be able to help them address resource availability issues, for example to facilitate sharing of personnel, equipment, funding, or other needs to best achieve SKR conservation goals.

**Table 2**. Existing management plans that address SKR.

| Plan Title | Originator | Date | Plan Type | Geographic Area |
|---|---|---|---|---|
| Draft Recovery Plan for the Stephens' Kangaroo Rat | U.S. Fish and Wildlife Service, Region 1 | 1997 | SKR Recovery Plan | Southern California (range-wide) |
| Riverside County Multiple Species Habitat Conservation Plan (MSHCP) | Western Riverside County Regional Conservation Authority (RCA) | 2003 | Multiple Species Plan | Western Riverside County |
| Framework Management and Monitoring Plan Ramona Grasslands Open Space Preserve San Diego County, California | Conservation Biology Institute, The Nature Conservancy | 2004 | Habitat Mgt. Plan | Ramona Grasslands Open Space Preserve |
| Area Specific Management Directives for Ramona Grasslands Preserve San Diego County | Conservation Biology Institute, County of San Diego Parks and Recreation | 2007 | Habitat Mgt. Plan | Ramona Grasslands Open Space Preserve |
| Stephens' Kangaroo Rat Habitat Management and Monitoring Plan & Fire Management Plan for RCHCA Lands in the Lake Mathews and Steele Peak Preserves | DUDEK, Riverside County Habitat Conservation Agency | 2007 | SKR Habitat Mgt. Plan | Lake Mathews and Steele Peak Preserves |
| Restoration Plan for Stephens' Kangaroo Rat, California Gnatcatcher, and Quino Checkerspot Butterfly Habitat for the Lake Mathews Project | RECON Environmental, Inc., BLM Palm Springs-South Coast Field Office | 2010 | Multiple Species Plan | Lake Mathews |
| Integrated Natural Resources Management Plan Naval Base Coronado, California | U.S. Navy | 2013 | INRMP | Remote Training Site Warner Springs |
| Integrated Natural Resources Management Plan for Naval Weapons Station Seal Beach Detachment Fallbrook | U.S. Navy | 2016 | INRMP | NWS Seal Beach Detachment Fallbrook |
| Joint Integrated Natural Resources Management Plan for Marine Corps Base and Marine Corps Air Station Camp Pendleton, California | U.S. Marine Corps | 2018 | INRMP | Camp Pendleton |
| San Jacinto Wildlife Area Land Management Plan Programmatic Environmental Impact Report | California Department of Fish and Wildlife | 2020 | Land Management Plan | San Jacinto Wildlife Area in Riverside County |

### 7.1.2. Regionally and Rangewide

A primary goal of this Plan is to better coordinate inter-reserve decision-making, such that management actions are prioritized where they most benefit the species as a whole, rather than treating each reserve as an independent and isolated entity. Ideally, the SKR Implementation and Technical teams will review rangewide SKR management needs at least annually, decide where management actions will best further SKR conservation goals, and help facilitate allocation of resources appropriately. Examples of rangewide decision-making to be made by the Implementation Team, with input from the Technical Team or stakeholders, may include deciding on where and when translocations should be planned, or where sharing of funds, personnel, or equipment may be required to help a reserve accomplish its priority management goals. Additional information and recommendations about the role of the SKR Technical and Implementation Teams in coordinating management and monitoring decisions are provided in Chapter 10.

## 7.2. Habitat Management

**Habitat management** includes any action intended to improve or sustain favorable SKR habitat characteristics by affecting vegetation composition or structure, soil characteristics, or ecological disturbance regimes. Appropriate **management tools** can be used to try to move conditions toward **desired habitat conditions**.

### 7.2.1. Desired Habitat Conditions

Management should strive to maintain the following conditions on SKR reserves, recognizing that SKR habitat is dynamic, with shifts in quality over space and time. Not all desired conditions or combinations of conditions can or should be attained everywhere at once, so long as conditions are not simultaneously unsuitable over much or all of a reserve or habitat unit. While habitat value and SKR populations will fluctuate from place to place and year to year, managers should avoid allowing widespread and simultaneous losses in habitat value, which could lead to erosion of genetic diversity and subpopulation extirpation.

**Vegetation Composition**

SKR prefer prairie vegetation dominated by forbs and grasses, with few if any shrubs (and no more than 30% shrub cover), few if any trees, and abundant bare ground. Forbs should be more abundant than grasses: On the Ramona Grasslands, Conservation Biology Institute (2007) found a forb:grass ratio > 2 in the highest quality SKR habitat. Some native plants associated with historical SKR conditions, such as perennial bunch grasses (*Nassella* spp.), are currently rare but would be desired. A broad diversity of annual forbs, both native and nonnative, is desired to provide seeds and shoots for SKR food and the open-ground conditions kangaroo rats prefer for most of the year. Thick cover of nonnative, annual grasses (e.g., many *Bromus, Avena, Lolium, Hordeum, and Taeniatherum* spp.) is not desired; and grasses or other herbaceous plants that produce dense thatch are especially detrimental.

Although SKR thrive in open vegetation lacking shrubs and other dominant perennials, some patchy inclusions of shrubs or perennial herbaceous vegetation may provide alternative food sources and other ecological benefits within SKR habitat, although this is not well supported by existing information. Having some summer annuals, such as asters (*Aster* spp.), tar plant (*Dienandra* spp.), and doveweed (*Croton* spp.), in addition to spring annuals may provide for broader food options, especially in years where the earlier winter-spring annuals are not productive. Likewise, although SKR are often found in areas completely devoid of shrubs, it is possible that some native shrubs, such as *Artemisia* or *Eriogonum*, may provide additional seed sources, especially in autumn, but again this is not strongly supported in the literature.

**Vegetation Structure**

All kangaroo rats require abundant exposed soil to accommodate their saltatorial locomotion, foraging for seeds on and beneath the soil surface, and sandbathing and chemical communication. Ideal SKR vegetation includes a variety of low-growing forbs that set seed, dry out, and disarticulate following spring green-up, thus providing abundant bare soil for much of the year. A useful rule of thumb for reserve managers is to maintain a roughly 50:50 bare ground:vegetation ratio following management treatments or during the dry season (late summer-fall) (B. Shomo, personal observations). Another rule of thumb is to maintain residual dry matter (RDM) measured during late summer-autumn of no more than 1,500 lbs/acre (Conservation Biology Institute 2007).

Although vegetation is often quite homogeneous across SKR habitat, some fine-scale patchiness is likely desirable, with some patches of denser forbs (or scattered shrubs) surrounded by sparser vegetation with more bare soil.

**Soil Characteristics**

SKR are associated with well-drained, friable, loamy soils (soils with relatively equal mixture of sands and silts, and lesser amounts of clay) on gentle slopes. Too much clay can result in hard (when dry) or sticky (when wet) properties that can impede burrowing and water drainage. Too much sand can result in loose conditions that don't support burrow structure well. SKR will use clay-loam soils, but generally at lower population densities than better-drained loamy soils (B. Shomo, W. Spencer, D. Shier and S. Montgomery, personal observations).

Soil water retention, which is generally higher in heavier clay soils, may cause burrow humidity above which SKR are adapted and which may cause seeds to become excessively mouldy. At the Ramona Grasslands, Spencer (personal observations) observed that SKR persisted through both wet and dry years on well-drained, loamy hillocks, whereas their populations spread into and contracted back from more poorly drained soils with higher clay content, depending on rainfall patterns. In dry years, active burrows were often found out on the flatter, more clayey soils, but not in wetter years.

Pocket gophers (*Thomomys bottae*) are stronger burrowers than kangaroo rats, and SKR readily use and improve on gopher burrows, which thereby facilitate use by SKR of heavier clay or otherwise less friable soils (W. Spencer and S. Montgomery, personal observations). Soil compaction by vehicles, heavy equipment, or trampling by livestock can impede water drainage and make soils hard for burrowing, and therefore may be detrimental to SKR habitat value. However, these same factors often result in favorable bare soil conditions; and SKR often burrow within or immediately adjacent to compacted soils, such as along trails and dirt roads. Brehme et al. (2019) found a positive association between SKR occupancy and soil compaction on Marine Corps Base Camp Pendleton over the range of values they measured, and hypothesized this may be because compacted soils may hold burrow structures better than looser soils. However, because soil compaction is also related to soil disturbance, bare ground, flatter slopes, and reduced shrub cover, which are also associated with SKR occupancy, this result does not necessarily indicate that SKR prefer compacted soils.

**Ecosystem Dynamics**

SKR is considered a “pioneer” or “disturbance-adapted” species that does well following vegetation disturbance by fire, grazing, or other factors. Prehistorically, SKR evolved with native ungulates such as pronghorn (*Antilocapra americana*) and bison (*Bison bison*) although there is little direct evidence that these species actually helped maintain the dynamic disturbance regime that SKR prefer (although bison and other grazers do play an important role in the ecology of numerous other kangaroo rat species in North America). Since European settlement, livestock grazing has helped maintain favorable disturbance conditions for SKR (since pronghorn went extinct in southern California by the early Twentieth Century and bison and other megafauna long before that). Frequent fire due to humans (including intentional fire use by native cultures and intentional and unintentional fires in more recent times) appears to have helped support favorable SKR conditions. For example, very frequent fire on Marine Corps Base Camp Pendleton associated with troop training exercises as well as prescribed fire appear to maintain favorable conditions on portions of the base.

SKR habitat management should strive to mimic a “natural” disturbance regime that helps maintain a favorable mix of habitat conditions across reserves and over time, subject to various management constraints and considering natural fluctuations in weather and other conditions.

## 7.2.2. Habitat Management Toolbox

This section describes available habitat management tools that can be used to attain desired SKR habitat conditions. They include alternative tools for managing vegetation composition and structure or for improving soil conditions, such as permeability, friability, or saturation. See Appendix E: Resources for the Land Manager for a compiled list of pertinent references, including those cited below.

The techniques described here are often implemented together in an integrated management plan with multiple objectives, which may include sustaining other rare or endangered species, controlling invasive plants, or restoring native plant communities. Any resource management plan should clearly state the management objectives, describe the treatments, evaluate potential tradeoffs (e.g., where improving habitat for one species may degrade habitat for another), and monitor the results. We recommend that monitoring data be carefully managed to track progress toward objectives, modify practices based on lessons learned, and provide continuity over time as reserve staff may change.

The information summarized here provides an initial introduction to SKR habitat management tools, which managers should build on with experience, insights from other managers, new scientific findings, and adaptive learning. To facilitate active information exchange and learning, we recommend establishing an online communications forum for SKR managers as part of the Coordination Structure section of this Plan and recommend close coordination with the SKR Technical Team.

**Grazing**

Livestock grazing, especially by sheep and cattle, is a favored SKR vegetation management tool. Kangaroo rats evolved with large, grazing and browsing ungulates, and livestock grazing may mimic some of the effects formerly caused by now absent native grazers (e.g., bison, pronghorn), including decreasing vegetation density and thatch and increasing exposed soil. Cattle grazing is used on some reserves as well as non-reserve SKR habitat areas in San Diego County, and managed sheep grazing is used on a number of reserves in Riverside County. In general, horses do not benefit SKR habitat due to their tendency to rip plants up by the roots, selectively eat forbs before grasses, and compact soil.

Grazing may be the preferred vegetation management tool where fire, another natural disturbance process, is not desirable due to air quality and safety concerns. Grazing may also have the co-benefit of economic returns where commercial livestock production is feasible, especially on larger reserves. However, this is uncommon in southern California due to generally poor forage conditions. Commercial cattle grazing helps maintain SKR habitat on private Rancho Guejito and the Lake Henshaw Grasslands, and has been continued as a successful management tool on portions of the Ramona Grasslands Reserve. At Ramona, commercial cattle production is considered viable largely due to improved forage where wastewater effluent spray irrigates patches of grassland (S. Tellam, personal communication cited in Spencer (2004)).

Where commercial livestock production is not an option, land managers may need to contract for grazing services. Commercial production is generally considered infeasible in Riverside County, where some reserve managers use managed sheep grazing to improve and maintain favorable SKR habitat conditions (B. Shomo, personal communication). The RCHCA manages sheep grazing using a simple rule of thumb: once grazing reduces vegetation cover to a 50% bare ground status, the sheep are shifted to a new area (B. Shomo, personal communication).

Reserve managers are encouraged to consult with a Certified Rangeland Manager, a local University of California Cooperative Extension Livestock Advisor, or a local Natural Resource Conservation Service (NRCS) Range Conservationist to help prepare or update grazing management plans to sustain desired SKR habitat conditions. A grazing management plan should address grazing species, intensity, timing, and rotations, as well as means of dispersing grazing intensity appropriately to achieve desired conditions, such as by using fencing and placement of salt and water sources, or by actively moving livestock. Seasonal timing can also be important--for example, to graze invasive plants before they set seed and to avoid grazing on wet soils, which may cause soil compaction and burrow collapse.

Effects of grazing should be monitored using a standardized habitat monitoring protocol and before-and-after photographs. Monitoring metrics indicative of desired habitat conditions may include residual dry matter (RDM) and ratio of forbs to herbs, as used on the Ramona Grasslands (Conservation Biology Institute 2007), or other easily monitored factors, such as percent bare ground (B. Shomo, personal communication).

On the Ramona Grasslands, the long-term cattle grazing regime has maintained suitable habitat conditions for SKR, which Conservation Biology Institute (2007) described as 20-50% bare ground with a forb:grass ratio > 2 in the highest quality habitat. Conservation Biology Institute (2007) recommended managing for residual dry matter (RDM) during late summer-autumn of no more than 1,500 lbs/acre and a target of less than 1,000 lbs/acre in core habitat areas (loamy grassland). Although SKR were sometimes found occupying areas with RDM over 2,000 lbs/acre, RDM of 3,000 lbs/acre appeared to be an upper threshold for suitable habitat. Based on monitoring results from Conservation Biology Institute (2007), the County of San Diego adopted the following RDM targets for grazing management: RDM of 800-1,500 lbs/acre on clayey grassland and 300-700 lbs/acre on loamy grassland. Note that these guidelines were based on the specific environmental conditions at the Ramona Grasslands, and may not apply elsewhere. In some areas, this intensity of grazing could have other effects, such as soil compaction, which further supports that grazing management plans should be carefully designed, monitored, and adjusted as needed to fit local conditions on any given reserve.

Cattle grazing has been effective in maintaining open grassland conditions (e.g., reduced residual dry matter, increased bare ground) for SKR in portions of Fallbrook Naval Weapons Station (S. Montgomery and C. Wolf, personal communications). However, grazing effects have varied over time with rainfall and herd size, and a prescriptive approach that specifically targets SKR habitat management has been elusive. Cattle grazing has not prevented expansion of coastal sage scrub into SKR habitat (C. Wolf personal communication via S. Montgomery).

Cattle grazing has also strongly affected SKR habitat conditions at Lake Henshaw/Warner Springs. Ungrazed areas typically exhibit dense non-native grasses and few if any SKR, whereas grazed areas support SKR populations (S. Montgomery, personal communication).

**Fire**

Fire is a dynamic tool to help maintain favorable SKR habitat conditions while also achieving other resource management goals. Prescribed burns may be used to reduce vegetation and thatch within areas that have higher than optimal perennial and annual vegetative cover to mimic historic natural habitat disturbances. Fire is a natural process in southern California, and thus, SKR has evolved with fire. Prior to human habitation, fires were the result of lightning strikes. The frequency of historic fire events are estimated at around 70 years closer to the mountain ranges (Keeley and Fotheringham 2001). Fire has been shown to increase species richness and cover of native forbs and increase in cover of native grasses, to decrease species richness and cover of invasive grasses and native shrubs, and increase richness but decrease cover of invasive forbs (Conlisk et al 2015). A study on SKR translocation that used fire, grazing and mowing to prepare receiver sites for the species found a native forb release on subplots treated with fire, beneficial effects on habitat lasted for 2 years and SKR translocated into the area settled in fire prepared subplots more than subplots prepared via grazing or mowing (Shier 2011, 2013, Shier and Swartz 2012). Used alone or as part of an integrated approach, fire can help control invasive plants, reduce hazardous fuel loads, restore historical disturbance regimes, improve forage and habitat for wildlife, and promote biodiversity. Fire can be used in conjunction with mechanical or chemical control methods to enhance their effectiveness, such as to reduce thatch for more effective herbicide applications, to improve access for mechanical treatments, and to stimulate seed germination. Combining fire with other treatment types can also prolong the time needed between treatments. See *The Use of Fire as a Tool for Controlling Invasive*

*Plants* (Cal-IPC 2006) for information on planning and implementing prescribed burns for a variety of management objectives, what to expect for control of different kinds of invasives, and the effect of fire on plant communities and soils.

Prescribed burning requires addressing safety and regulatory liabilities during planning and implementation. Land managers within **State Responsibility Areas (SRA)** should apply to the CAL FIRE Vegetation Management Program to take advantage of CAL FIRE's extensive experience and to ensure that all necessary regulations are met. The Vegetation Management Program (VMP) is a cost-sharing program that focuses on the use of prescribed fire and some mechanical means for addressing wildland fire fuel hazards and other resource management issues on State Responsibility Area (SRA) lands. Participation in the Vegetation Management Program allows private landowners to enter into a contract with CAL FIRE to use prescribed fire to accomplish a combination of fire risk reduction and resource management goals. When approved as a VMP project, CAL FIRE assumes the liability for conducting the prescribed burn. Given available resources, CAL FIRE will provide assistance and do the burning at no cost to the land owner.

**Herbicides**

Herbicides can be used to control non-native grasses and other invasive plants, such as stinknet (*Oncosiphon piluliferum*). In SKR reserves, herbicides are used mainly in limited, targeted applications rather than broadcast over large areas. Before using herbicides, we recommend consulting with a licensed Pest Control Advisor (PCA), read the product's Material Safety Data Sheet (MSDS), and take the necessary safety precautions. Apply herbicides using recommended label rates.

Stinknet is a noxious winter annual composite that grows in dense clusters that has heavily infested counties in California between Los Angeles and San Diego. The plant can spread explosively in wet winters, with emergence and growth beginning in November and continuing through May, and seed dispersal from March through June. During growth the plants can cause severe allergic reactions, both dermal and respiratory. Dried dense patches are highly flammable, and the smoke is caustic. Stinknet is not palatable to livestock and the small seeds may be dispersed by attaching to the hair or feet of livestock.

When controlling stinknet, the plant's continuous emergence over several months requires repeated manual removal and/or repeated post emergent herbicide applications. If the stinknet population is allowed to spread for two or more years, manual removal becomes extremely difficult. Properly applied, several herbicide and surfactant combinations can achieve 90% reduction of stinknet and may provide good long-term control (McDonald 2019, Scheuring 2020). In addition, several pre-emergent herbicides are currently being tested on stinknet populations with results expected in the next few years. Herbicides should only be applied by individuals that possess a qualified applicator license while following label directions.

It is important for the land manager to understand risks to wildlife from both toxicity and exposure when developing an invasive plant management plan that includes the use of herbicides. Cal-IPC's *Best Management Practices (BMPs) for Wildland Stewardship: Protecting Wildlife When Using*

*Herbicides for Invasive Plant Management* (Cal-IPC 2015) offers guidance to land managers drawn from experience for protecting birds, mammals, insects, and aquatic species.

As with any habitat management treatment, use of herbicides should be planned, documented, and then followed up with monitoring. Mapping invasive plant populations is critical for strategic management and monitoring and essential for effective early detection-- knowing where a plant currently grows is the foundation for knowing where to survey for new occurrences. For help planning and implementing an invasive plant control program, refer to the resources below and experienced land managers in your area.

**Mechanical Treatments**

Mechanical habitat treatments include mowing, discing, scraping, raking, pruning, or other methods of altering vegetation composition and structure by machine or by hand. These may not be considered as ecologically “natural” as grazing or fire, but they can nevertheless be effective tools in certain circumstances, often in combination with other habitat management tools. In some cases, grazing or fire may not be viable options on a reserve, especially near urbanized areas, due to air quality, perceived risks, land-use regulations, or public objections. In such cases, mechanical treatments, possibly in concert with herbicide use, can be used to reduce invasive vegetation and thatch. Mechanical treatments like mowing and raking can also be alternated with prescribed fire or herbicide use where they are allowed, which can increase effectiveness of these alternative tools.

Where grasses and thatch are dense, de-thatching with a cyclone rake or surface scraping of the soil with an attachment (e.g., a steel plate, grate, or weighted section of chain-link fence) dragged behind a tractor in late summer or fall, after vegetation has senesced and dried, can be an effective method for creating bare ground and encouraging forb growth. This should generally be restricted to unoccupied, potential SKR habitat prior to a translocation or reintroduction attempt (S. Montgomery and W. Spencer, personal observations) to avoid potential damage to occupied burrows. SKR will use such scrapes as travel corridors and for foraging along their edges. S. Montgomery (personal communication) recommends creating scrapes 2-6 m wide in a grid pattern with roughly 5-10m spacing, depending on vegetation density, terrain, and budget. This creates favorable habitat heterogeneity and microtopography, with criss-crossing scrapes providing easy movement and foraging access by SKR over the area.

Mowing is sometimes used in lieu of or in concert with grazing and fire treatments. Mowing is best done before annual grasses or other undesirable plants set seed, and may be best performed multiple times per year, especially if not combined with other treatments (B. Shomo, personal communication). Otherwise, mowing could be followed by raking to reduce thatch. Mowing annually or less frequently without also using fire or raking can add to undesirable thatch build up.

Manual removal or pruning of shrubs may be useful where shrub cover is encroaching into potential SKR habitat. Stinknet can be manually dug out as soon as it is recognized. It is important to remove the plants before they develop mature seeds. Stinknet plants can be mechanically removed either by hand pulling (with gloves, the plants stink and are allergenic), using mowers, or string trimmers. Treatments need to be repeated, as multiple cohorts of plants will continue to flower throughout the growing season and small plants will flower when taller plants have been cut down. Equipment needs to be thoroughly cleaned to remove attached soil and seeds to avoid introducing the plant to new areas.

**Soil Decompaction**

Although SKR may be associated with disturbances that tend to compact soils (e.g., human or livestock trampling, trails and dirt roads), in rare circumstances soil compaction, if extensive, can be detrimental to habitat condition by creating large areas devoid of vegetation or by making soils too hard for burrowing. In such cases, methods for decompacting soils may be applied, generally as part of a comprehensive ecological restoration plan and only in areas currently not occupied by SKR, to avoid potential for direct harm to SKR. The goal should be to improve soil friability and porosity to encourage favorable vegetation growth and burrowing potential.

If decompaction is recommended, the restoration plan should consider the depth of decompaction methods relative to soil layers, SKR burrow depths, depth of existing compaction, and the desired outcomes in terms of soil structure (e.g., coarsely broken to powdered). Decompaction can be attained using an array of tractor or bulldozer attachments, such as cultivators, ripping teeth, or disc harrows. Such mechanical methods should be timed when soils are slightly moist (not wet or dry).

An alternative to mechanical methods may be biological methods of soil decompaction, such as by encouraging gopher or ground squirrel occupancy, prior to vegetation restoration. These stronger burrowers can help naturally decompact and aerate soils, and they create burrows that SKR can use and improve for their own use. Ground squirrels can be encouraged to establish in open habitats by establishing cover piles (brush or rubble, roughly 1-2 m diameter and 1 m high) at roughly 50m spacing, which squirrels use as cover from which to initiate burrowing activity. This technique is routinely used to encourage ground squirrel occupancy to benefit burrowing owls (*Athene cunicularia*), especially prior to owl reintroductions (C. Schaefer, personal communication). If attempted in SKR habitat, this method should be treated as an adaptive management experiment with careful monitoring to ensure ground squirrels do not harm SKR.

In addition, managers could experiment with mulches, ground covers, plantings, or other botanical means of decompacting soils. Such experiments would best be implemented within a before-after/control-impact (BACI) monitoring design to compare effectiveness of alternative approaches .

**Hydrological Improvements**

In rare circumstances, increased runoff or other changes to natural hydrological conditions due to human land uses may result in flooding or soil saturation in potential SKR habitat. Excess moisture can harm SKR below ground by destroying seed stores (e.g., due to mold) or wetting SKR pelage, causing hypothermia. S. Montgomery (personal communication) has observed inundation of occupied SKR burrows following several days at lower elevations at Fallbrook Naval Weapons Station. The potential for such flooding should be considered when selecting areas for habitat rehabilitation.

Where excess runoff from adjacent land uses other hydrological impacts may dampen soil in SKR habitat, various flood control or drainage improvements, such as dirt berms, diversion ditches, or French drains, may be recommended with input from a hydrological engineer. This is likely to be necessary in rare situations where SKR habitat directly abuts urban areas, irrigated lands, or other sources of excess runoff.

### 7.2.3. Ecological (or Vegetation) Restoration

Ecological or vegetation restoration is the systematic application of a suite of management tools to convert an existing, generally undesired, ecological state to a different, desired, ecological state, such as converting Mediterranean annual grasslands to a more native condition of perennial grasses and forbs. Complete restoration of native SKR habitat by removing nonnative species and restoring the full range of original forbs and native grasses is generally considered infeasible due to the overwhelming presence and competitive advantages of naturalized Mediterranean grasses in the system. However, restoration toward a more native and desirable SKR habitat condition is possible where conditions are currently far from the desired condition.

Native grasslands (or prairies) in California are among the most endangered ecosystems in the United States, and they continue to decline. Invasion by woody and nonnative species often occurs on conservation lands that have been protected from grazing and other disturbances (Barry et al. 2020). The benefits of grassland restoration include improved habitat for SKR as well as birds, pollinators, butterflies and other beneficial invertebrates. Established native perennial grasses provide long-term suppression of noxious weeds, even in years that are favorable for weed growth. They are extremely long-lived and act as ecosystem engineers, providing green forage throughout the dry season; moisture, aeration, and erosion control for the soil; and sequestering carbon in their extensive root systems (Stromberg and Kephart 2020).

Any attempt at restoration of SKR habitat should be carefully planned by experts in ecological restoration according to well-researched restoration guides. Because ground disturbance and soil decompaction may be required, restoration would best be applied where SKR are currently absent, such as prior to a reintroduction effort, to avoid direct harm to individuals or their burrows and seed stores. Restoration of unoccupied areas adjacent to occupied areas can also facilitate natural population expansions. Restoration efforts will likely require repeated treatments of various types and careful monitoring of results, with adjustments over time. Guidance on reducing nonnative species and thatch and for appropriate native seed mixes are available.

Plant palettes will vary with regional differences in soils and climate conditions, and care should be taken to use relatively local seed sources (e.g., from the same ecoregion or watershed if possible) to account for local adaptation, avoid gene pool contamination, and increase probabilities of success. For example, needle grasses may be a preferred SKR habitat component, but are easier to establish and sustain in coastal areas than more arid inland areas. Managers should work with a local Resource Conservation District (RCD) or University Extension specialist to develop a suitable plant list for a location, which should include both spring and summer annuals and potentially some shrubs for diversity and additional seasonal food sources. Consult the California Native Grasslands Association's Grassland Restoration and Management Resources website for additional recommendations on seed selection and restoration methods.

Allen and Hilbig (2011) conducted research at Lake Mathews on restoration of exotic annual grassland to SKR habitat. They found that the removal of exotic grasses through the use of glyphosate and subsequent irrigation resulted in the establishment of broadleaf weeds, due to space and nutrients becoming available. Once the broadleaf weeds were established, the recolonization of exotic grasses was limited. Some natives were more competitive than others, suggesting the following competitive hierarchy: Exotic grasses > Broadleaf weeds > *Layia platyglossa* (persistent native) > *Lasthenia californica* ≈ *Amsinckia menziesii* (persistent native) >> *Plantago erecta*. From these results the authors recommend the use of herbicides to control broadleaf weeds and exotic annual grasses, and planting a diversity of native forbs (a 4-species mixture was used in this study) to result in a higher cover of native vegetation.

# 7.3. Population Management

Providing good habitat does not ensure population persistence or expansion, because populations also respond to other threats, from inbreeding depression to catastrophic events. Given the great degree of habitat fragmentation and dispersal barriers that exist within the SKR's range, animals that may have been locally extirpated for any number of reasons may be unable to recolonize them even if the habitat is suitable and other threats controlled. This section presents desired SKR population conditions and management tools that should be considered when direct intervention may be necessary to achieve them--i.e., when habitat management alone may not be enough.

## 7.3.1. Desired Population Conditions

To the degree feasible, management and monitoring should strive to achieve and track progress toward the following conditions concerning SKR population distribution, abundance, connectivity, and genetic diversity, recognizing that populations are naturally dynamic and can fluctuate dramatically in response to weather and other conditions. *These desired population conditions should be considered preliminary and subject to revision based on new data and spatially explicit metapopulation modeling.* Given the current state of information on SKR populations, spatially explicit population modeling--for example using HexSim (Schumaker and Brookes 2018)--could shed more light on the relative benefits of, for example, improving habitat connectivity versus increasing local population sizes, or performing reintroductions and other direct population manipulations.

Due to both natural and human-caused habitat fragmentation, SKR appear to be surviving as a collection of several regional metapopulations, with some subpopulations and clusters of subpopulations probably isolated from others with no inter-population dispersal or gene flow. This situation should be considered in interpreting the following desired conditions.

**Population Size and Trends**

Recognizing that SKR populations will naturally fluctuate over time at multiple spatial scales, management should strive to keep total SKR population size generally stable or increasing rangewide and within each of the five SKR ecoregions (see Chapter 3) measured over roughly 5-7 year periods (to account for natural climate-driven population fluctuations due to ENSO[5]). Even though local population contractions, expansions, extinctions, and colonizations are likely, at region-wide and

[5] El Niño and the Southern Oscillation, also known as ENSO is a periodic fluctuation (i.e., every 2–7 years) in sea surface temperature (El Niño) and the air pressure of the overlying atmosphere (Southern Oscillation) across the equatorial Pacific Ocean. It strongly influences wet-dry weather cycles in southern California.

rangewide scales the sum of these processes across multiple population units should show stable or increasing trends when averaged across all units.

**Occupancy Patterns**

Given that 100% of suitable SKR habitat will never be saturated by SKR due to their natural patchiness and population dynamics, management should strive to maintain SKR occupancy over a certain percentage of modeled suitable habitat in any given year, to be established based on initial presence-absence monitoring data analyzed using percent area occupied (PAO) methods (MacKenzie and Reardon 2013). Note that (1) PAO results are highly scale-dependent (i.e., the size of the polygons within which species presence or absence is determined effects PAO estimates, and therefore must be standardized) and (2) that precision of PAO estimates is highest in middle ranges of potential occupancy (i.e., between about 20% and 80% of polygons occupied) than at the extremes (i.e., near 0% occupied or close to 100% occupied). The power analysis described in Section 8.3 will therefore be used to determine the optimal scale for PAO monitoring and for establishing the percent occupancy goals rangewide and perhaps within each SKR ecoregion.

**Population Connectivity**

Given the current degree of SKR habitat fragmentation that occurs at all spatial scales--from within reserves to regional and rangewide patchiness--improving functional connectivity (e.g., facilitating dispersal and gene flow) is a high priority at all relevant scales to sustain and recover the species. Population connectivity should therefore be functional at each of these scales: **local** (within a reserve), **population unit** (within clusters of suitable habitat patches that are within easy dispersal distance of one another), **subpopulation** (within networks of population units that experience at least occasional inter-unit dispersal), to **rangewide**. Ideally, all local populations and subpopulations should be functionally connected by dispersal (gene flow) to at least one other subpopulation, such that the entire rangewide SKR population is demographically and genetically connected as an interacting network that experiences gene flow from one end to another over many generations. A rare exception to this goal might exist if genetic and phenotypic analyses demonstrate that connectivity is unnecessary or even undesirable for a given population due to local or regional genetic adaptations. In the case of clearly demonstrable local or regional adaptation, forcing gene flow to a population could theoretically compromise its genetic adaptations. Otherwise, rangewide population connectivity should be the ultimate, albeit a difficult, goal.

**Genetics**

There should be no further loss of genetic diversity within the species as a whole nor within any local population, subpopulation, or ecoregion. Unless analyses clearly demonstrate that there is local adaptation in the gene pool of an isolated SKR population, such that gene flow into that population may have deleterious consequences, every SKR population and subpopulation should experience bidirectional gene flow with at least one other population unit; and over the SKR range, gene flow should connect all subpopulations into a functional metapopulation.

## 7.3.2. Population Management Toolbox

**Dispersal Improvements**

Population connectivity and gene flow are ideally maintained by natural dispersal as facilitated by functional habitat connectivity or dispersal corridors between habitat patches. Where absolute barriers created by humans prevent dispersal and gene flow between subpopulations, restoring or improving connectivity is a priority management objective. This may entail improving or creating movement corridors and crossing structures to help SKR negotiate barriers. Examples of improvements include road overcrossings (e.g., wildlife bridges) or undercrossings (e.g., culverts) or creating corridors of suitable dispersal habitat (e.g., dirt trails or roads) across otherwise non-suitable habitat (e.g., between agricultural fields).

Little scientific information exists concerning SKR use of crossing structures, but available information for SKR and other kangaroo rat species suggest that they may use large culverts or other undercrossing structures, especially if they have a natural dirt floor and some form of hiding cover, such as dead shrubs, is provided inside (Shier and Gray 2020); Shier and Gray, 2020). For SKR, it is important that habitats at either end of the structure have the open conditions favored by SKR, as dense vegetation or thatch would prevent them from accessing the road-crossing structure. In some cases, it may be useful to use mechanical management tools, such as mowing or string trimming, to provide an easy access route to and from the crossing structure if habitat immediately on either end of the structure is not otherwise suitable.

The effectiveness of any such improvements should be carefully monitored, such as by using a before-after/control-impact (BACI) monitoring design as described in Section 8.6. Research Monitoring.

**Translocation and Reintroduction**

**Translocation** is any human-mediated movement of animals from one location to another. It may include **reintroduction** (moving animals into suitable but unoccupied habitat areas), **captive breeding** (bringing animals into captivity, building a breeding colony, and then translocating individuals back into the wild), or translocation for **genetic augmentation** (moving animals into an existing population to add genetic diversity).

Reintroduction may be recommended into suitable but unoccupied habitat patches large enough to support a subpopulation but that are unlikely to be naturally recolonized via dispersal. Ideally, the source population should be large and robust, unless the source population is being moved or "rescued" from a site prior to its development or another action that could kill the individuals or remove their ability to survive there. Absence of SKR should be confirmed in the receiving site by surveys that capture no SKR after at least 5 nights of standard protocol trapping throughout the patch.

Translocating SKR into an already occupied area is generally not advised, unless the receiver site has a low population density, the reasons for the low density are first addressed (e.g., by improving habitat quality). Ideally,  the source animals should be obtained from a large population that can persist following removal of some individuals, from an area where individuals would be impacted such as from a planned development. Typically, to minimize impacts to source populations where no impacts are planned, no more than 10% of adults or 20% of young of the year are collected for translocation efforts. Alternatively animals could be sourced from a captive population maintained for this purpose.

Shier and Swaisgood (2012, Shier 2016) studied translocation methods for SKR and found that kangaroo rats translocated with familiar neighbors traveled shorter distances before establishing territories, had higher survival rates, and had significantly higher reproductive success than kangaroo rats translocated with unfamiliar neighbors. Based on this and other experience with SKR translocation and reintroduction, Shier (2016), developed a strategy for successful SKR translocation (Appendix I: Shier 2016 Translocation Model) that should be followed for any translocation proposed under this plan.

**Genetic Augmentation**

Genetic rescue or augmentation involves introducing individuals from one population into another that is suffering from low genetic diversity to increase the genetic diversity and hopefully fitness of the receiving population (Frankham et al. 2017). Genetic rescue has been used successfully in many laboratory and agricultural species (e.g., heterosis; Sinha & Khanna 1975), and is a conservation tool that has led to population recovery of Florida panthers (Johnson et al. 2010), adders (Madsen et al. 1999), bighorn sheep (Hogg et al. 2006), prairie chicken (Westemeier et al. 1998), and wolves (Fredrickson et al. 2007). However, a risk of genetic rescue that must be evaluated is the potential for inter-population mating to lead to outbreeding depression, which is the reduction in reproductive fitness of offspring or subsequent generations following the attempted crossing of populations (Frankham et a. 2011). This may result from combining individuals from populations with fixed chromosomal differences, the disruption of genetic adaptations to differing environments, or the disruption of genetic differences among populations that have arisen from long periods of isolation and genetic drift (Frankham et al., 2011, Frankham et al., 2017). Frankham et al. (2011) show that outbreeding depression is predictable and has a low probability of occurrence when the two crossed populations belong to the same species, have no fixed chromosomal differences, had some gene flow in the last 500 years, and occupy similar environments. Genetic data from SKR translocation has shown a remarkably high level of genetic differentiation among the three source sites despite their close geographic proximity. Nevertheless, fitness data from the receiver site suggest no outbreeding depression (Shier et al, submitted).

Hedrick and Fredrickson (2010) outline guidelines to assess whether genetic rescue is warranted and suggest using data from a captive population can be used to evaluate fitness of crossed populations to understand the risks of outbreeding depression and the benefits of genetic rescue. Further research is needed to determine whether, or in which circumstances, genetic rescue may be necessary and beneficial for SKR (Sinha and Khanna 1975, Westemeier et al. 1998, Madsen et al. 1999, Hogg et al. 2006, Fredrickson et al. 2007, Johnson et al. 2010, Hedrick and Fredrickson 2010, Frankham et al. 2011, 2017).

## 7.4. Direct Threat Management

This section addresses ways to mitigate direct threats to individual SKR or SKR populations in addition to the general threats posed by reduced habitat quality and habitat fragmentation addressed above. Direct threats include things such as artificial lighting, exotic predators, roadkill, or flooding.

### 7.4.1. Desired Conditions

On SKR reserves, there should be few if any direct threats to the fitness of individual SKR, and none to any local population as a whole, that can be avoided by management. Below are desired conditions for those direct threats identified by SKR managers as present or potentially present on their reserves, (Appendix D: Threats Survey Summary).

- *Artificial light* sources should not penetrate into SKR habitat, especially at ground level.
- *Wildfire* regimes should be within the natural range of variation expected for the region and vegetation communities on a reserve in terms of fire frequency, intensity, and seasonality, unless deviations from the natural regime are specifically intended to help achieve desired SKR habitat conditions (e.g., more frequent than natural fire to reduce shrub encroachment, or earlier spring fire to reduce invasive plant seed banks).
- Severe and prolonged *drought* should not reduce SKR food sources to the degree the population is threatened with extirpation or severe inbreeding depression (although managing to avoid this threat may be beyond management control).
- *Roadkill* should be minimal or nonexistent on any roads that bisect or are near any SKR reserve, and no road should present a barrier to SKR dispersal within or between reserves.
- Traffic *noise* from roads should not exceed levels expected to interfere with SKR communications (foot drumming), cause stress to resident animals, or otherwise threaten the fitness of a population.
- There should be few to no *exotic predators* (e.g., house cats) in reserves, and nonnative predation should be extremely rare to nonexistent.
- *Pesticide* exposure (especially rodenticides) should be nonexistent on reserves, except for limited herbicide use according to approved applications as needed to control invasive plants.
- *Flooding or soil saturation* from extreme, prolonged rainfall or especially due to unnatural ground or surface water inputs (e.g., urban runoff or excess irrigation from adjacent lands) should be rare to nonexistent within potential SKR habitat.
- Discing or other *mechanical treatments* that disturb subsurface soil or collapse rodent burrows (e.g., for weed abatement or pasture improvement) should be prohibited in potential SKR habitat except as part of a comprehensive habitat restoration effort, and then usually only when SKR are confirmed to be absent, such as to prepare habitat before an SKR reintroduction attempt.

## 7.4.2. Threat Management Toolbox

For many of the threats listed above and in the SKR Threats Assessment, there may be no well-researched or established mitigation or management methods that are effective and reasonable. For a few threats, we provide some preliminary suggestions for minimizing or mitigating their effects that should be discussed by the SKR Technical Team and might be tried by reserve managers. If these are attempted, it should ideally be done in a carefully monitored manner to ascertain effects and effectiveness. In other words, most direct threat mitigation techniques should be treated as experiments as part of a well-conceived adaptive management program, as described below in Section 8.6 Research Monitoring.

- Mitigating light pollution within SKR reserves entails at least minimizing or eliminating artificial light sources at reserve facilities. Perhaps more important, but also more complicated, it likely means reducing offsite light inputs into habitat, which requires working with other entities. A wealth of information exists that should be consulted for how to reduce incidental light within wildlife reserves, including working with nearby landowners to eliminate unnecessary light sources, lower light intensity, reduce duration of night lighting, screen lamps to focus light where it is needed but not into wild habitats, and switching to light sources low in blue, violet, and ultraviolet wavelengths. See (Commonwealth of Australia 2020) for stepwise guidelines and prescriptions for reducing light effects on wildlife, and Gaston et al. (2012) for a scientific review of methods for mitigating their impacts.

- Every reserve should have a **fire management plan** that specifies how both wildfire and prescribed fire will be managed for resource values, including SKR habitat values. The plan should clearly map and describe where fire control measures are advised or prohibited, such as not bulldozing fire lines through occupied SKR habitat.

- Reserve managers certainly cannot control weather cycles or climate change, but perhaps they can anticipate their potential effects on SKR and consider contingency plans in the event that severe, prolonged droughts or intense, prolonged rainfall threatens to extirpate or greatly reduce local populations. Contingencies could potentially include translocation into better but unoccupied habitat areas or temporarily removing animals into captivity until a threat (e.g., flooding) has subsided. However, these “long-shot” and potentially costly endeavors are expected to be rarely recommended, and if attempted should again be treated as management experiments with careful monitoring.

- Where there is reason to believe that SKR are frequently crossing paved roads, occasional daytime roadkill surveys and nighttime road surveys (e.g., driving slowly on nights without moonlight using headlights and spotlights to spot kangaroo rats) might be helpful in identifying where there are significant problems with roadkill or barrier effects. If particular crossing points can be identified (for example where a dirt road or trail that facilitates SKR movements intersects a paved road) consider structural modifications that could deflect SKR away from crossing above ground and funnel them to existing or new undercrossing structures, such as broad culverts.

- Predation by free-ranging domestic animals, especially house cats, may be a localized threat to some SKR populations, but attempting to mitigate this (e.g., by cat removal or enforced restrictions on free-ranging animals) could be highly controversial and may increase resentments by local citizens to reserve practices. Whether and how to deal with this problem should be a topic of discussion by the SKR Technical Team.

- Excess predation by native predators is unlikely to be a problem except during the initial period following a translocation when animals are not yet adapted to their new environment. Coyotes, barn owls, and great horned owls have been shown to adversely affect introduced SKR populations without avoidance measures (Shier 2016). Consult Shier (2016) and seek advice from the SKR Technical Team for methods to minimize predation, which may include SKR enclosures that protect them from predators as well as techniques like adding mountain lion urine to the area (to deter coyotes or bobcats) or using great horned owl decoys and calls (to deter barn owls).

# 8. SKR Monitoring Strategy

The goals of the SKR Monitoring Strategy are to inform SKR conservation actions and to facilitate regular updating of information about habitat and population status and trends. Monitoring data on SKR habitat, population parameters (e.g., occupancy, density), threats, and genetics will be standardized, managed, and analyzed in the SKR Adaptive Management Cycle (as described in Chapter 9 and shown in Figure 10).

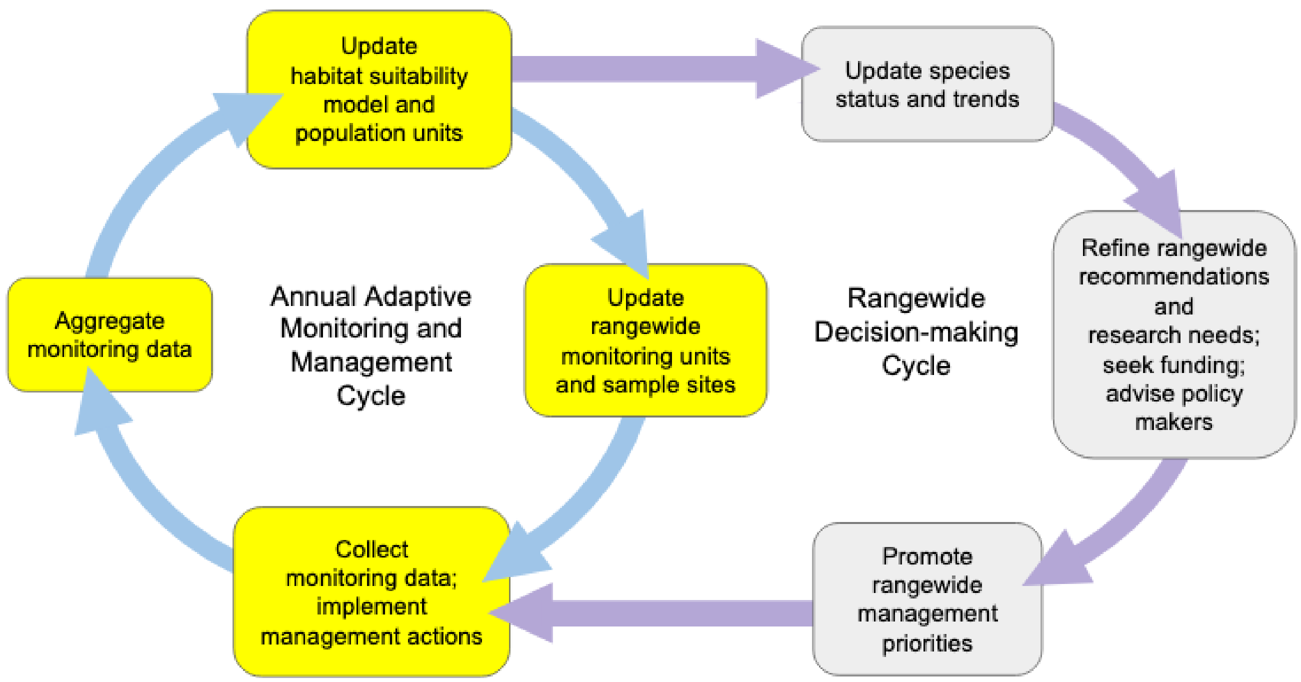


**Figure 10**. The SKR Monitoring Strategy is essential for the highlighted steps in the Adaptive Management Cycle.

The monitoring strategy is designed to:

- Coordinate and maintain a network of rangewide monitoring sites to collect comparable long-term datasets for a suite of common SKR population and habitat variables.
- Provide a standardized sampling approach for rangewide tracking or SKR status and trends using occupancy (PAO) and other population metrics.
- Leverage existing monitoring efforts to the degree feasible without adding excessive burden to managers.
- Use the habitat model to track changes in amount and quality of habitat across the range and in each SKR ecoregion, and to provide a spatial foundation for SKR population estimation.

- Provide metrics for evaluating the efficacy of conservation measures and determining when and where management interventions are needed (e.g., habitat improvements or population translocations).
- Identify research and funding priorities to support adaptive management decisions.

Although most aspects of the program must be standardized and implemented consistently, we intend the monitoring program to evolve somewhat as new information emerges, data are analyzed, and monitoring questions change (Lindenmayer and Likens 2009). The monitoring program must be closely coordinated with the Data Management Strategy, because the data fields and how data are collated, shared, and used are integral to successful monitoring, and vice-versa.

Implementing this program will require new resources or possibly redistribution of resources to accomplish rangewide goals. This should be addressed early during implementation by the SKR Implementation Team, which will determine how to balance capacity, resources, and monitoring needs amongst the partners. Also, data from the first few years of monitoring will be used to test and refine the overall sampling strategy in an adaptive manner until a fully standardized system is operating.

## 8.1. Overview of Monitoring Approach

The SKR Rangewide Monitoring Strategy integrates habitat, population, and genetic monitoring to provide an understanding of the SKR's status and trends, responses to threats and disturbances, and the effectiveness of management actions. Monitoring is already being conducted by SKR managers on reserve areas throughout much of the range (Appendix F: Existing SKR Monitoring Efforts). This Strategy builds on these existing programs by expanding and coordinating sampling rangewide, standardizing data collection protocols, instituting a central database and Data Management Strategy, and adding rangewide genetic monitoring.

The regularly updated **habitat model** provides the spatial foundation for quantifying habitat quality, quantity, and distribution; and by correlating field estimates of SKR occupancy and density with habitat quality, the map may be used to track rangewide patterns in SKR abundance. Modeled **habitat values** will be regularly updated and thresholded into habitat classes (e.g., high, medium, and low quality) for tracking changes and for allocating SKR **occupancy** and **density** sampling. Intersecting the habitat suitability map with SKR occupancy data will be used to update the **population units** introduced in Chapter 4 and the spatial sampling units for occupancy sampling. The estimated area of occupied suitable habitat can thus be reliably updated over time to track population trends by region as well as rangewide. Similarly, the total area of predicted suitable habitat (whether occupied or not) can also be tracked over time.

The population monitoring approach draws on and supplements the occupancy sampling and density index approach developed by USGS on Marine Corps Base Camp Pendleton (Brehme et al. 2006, 2019, 2011) (Table 3), which uses a PAO modeling design (MacKenzie and Reardon 2013) implemented across a large number of sample plots (grids) within high-quality SKR habitat. In addition, some additional "discovery sampling" is performed in suitable (but generally lower quality) habitat not known to be occupied to discover if it is actually occupied, or has recently been colonized. Each sample plot is trapped with 25 traps in a 5 x 5 array at ~10-m inter-trap spacing (e.g., on a 50 x 50m grid) for up to 4 consecutive nights (note: the specifics of the grid design and scheduling may change for rangewide monitoring purposes based on the PAO power analysis discussed in Section 8.3) A **population density index** was also developed using capture-recapture modeling methods on the resulting data and may also be used in rangewide monitoring.

This rangewide Plan adopts with some revisions this basic PAO approach used on Camp Pendleton at a much larger scale. The rangewide scope of the sampling strategy introduces some complications due to the high degree of habitat fragmentation and large number of patches involved, gradations in habitat quality, unknown occupancy status of many patches, and complex land ownership patterns across the range. Additional analyses of existing data, as well as new data to be collected early in Plan implementation, will be needed to refine the PAO sampling design introduced in Section 8.3.

The occupancy and density index methods will be supplemented with genetic sampling to provide deeper insights about population structure, connectivity, and **effective population size ($N_e$)**. Hair samples will be collected from each captured SKR and used to estimate $N_e$, which may be both more informative and less costly in the long-term than capture-recapture density estimates, and therefore might replace them in the future. The Camp Pendleton monitoring plan also provides a model framework for statistical analyses of trends in occupancy as well as the effects of habitat and environmental variables and management actions on SKR populations, providing an excellent basis for the Rangewide SKR Monitoring Strategy.

**Table 3.** MCB Camp Pendleton SKR monitoring protocol elements (Brehme et al. 2019). This Plan builds on and supplements these protocols at the rangewide and ecoregional scales using the new habitat suitability model.

| Protocol Element | Purpose(s) | Procedure(s) | Timing |
|---|---|---|---|
| Habitat Suitability Model | To determine spatial extent of occupied habitat to define annual SKR monitoring area. | Current knowledge of SKR habitat associations & distribution on MCBCP. | Program Optimization 2011. |
| | To define Discovery Area | Use of GIS layers to map potentially suitable SKR habitat (soils, slope, vegetation, impact area boundaries). | Program Optimization 2011. |
| Sample Allocation | Optimize sample allocation for highest power to detect changes over time and greatest coverage of known SKR habitat over time. | 125 plots in Monitoring Area (100 permanent and 25 new every year) | Yearly |
| | Discovery of new populations | 25 plots in Discovery Area (new each year) | Yearly |
| Sampling Protocol | To monitor trends in potential habitat areas occupied by SKR, estimated density within and among strata. | Burrow/Sign Searches + Live-trapping in randomly chosen permanent sample plots ( 50 $m^2$) | Yearly |
| Burrow/ Sign Search and Habitat Characterization | To determine presence or absence of kangaroo rats | Complete survey of sample plots for any potential kangaroo rat burrows or sign | Late summer and Fall (Oct-Nov), Yearly |
| | To collect habitat covariate data to model, better understand & predict SKR habitat relationships | Survey habitat characteristics thought to be associated with SKR presence. | |
| Live-trapping surveys | To confirm presence or absence of SKR. Produce metric of density. Calculate detection and capture probabilities for models. | live-trap for 2+ nights with standard 25 trap grid | Late summer and Fall (Oct-Nov) |
| Analyses | Total area (ha) of habitat on MCBCP occupied by SKR. Probabilities of SKR occupancy within and among strata.<br>Density within and among strata<br>Multi-year: patch occupancy and extinction (i.e. metapop. growth rate)<br>Model habitat and other covariates for value in predicting SKR occupancy, detection, density, colonization, & extinction. | Program PRESENCE or equivalent: Occupancy[1,2,3] and Point Count Model [4] (all). Program MARK (density index) | Yearly (all) |

[1]MacKenzie et al. 2002, [2]MacKenzie et al. 2003, [3]Royle 2004, [4]Royle and Nichols 2004

# 8.2. Habitat Monitoring

Habitat monitoring will be performed in two major ways: (1) using the SKR habitat model to estimate the rangewide distribution and abundance of suitable habitat, and (2) collecting standardized field metrics of habitat quality based on vegetation and soils conditions. The field methods should begin with those adopted for use by USGS on MCB Camp Pendleton (Brehme et al. 2019) perhaps supplemented by a visual assessment method (e.g., Relevé) to standardize rapid field evaluation of habitat quality without the need for intensive data collection and statistical analysis.

## 8.2.1. Modeled Habitat Evaluation

This Plan proposes to use the updateable habitat model as a foundation for tracking changes in habitat quality and distribution and SKR population distribution and size in order to regularly update the assessment of species status and trends. However, the process for updating the predictor variables derived from satellite imagery and other sources, re-running the five ecoregional habitat models, thresholding modeled habitat values to update maps of habitat suitability strata, and updating population occupancy and the spatial sampling units is complex and highly technical. We therefore recommend a small committee of modeling, programming, and GIS experts to develop a streamlined and perhaps automated method for performing these updates, along with a training and technology transfer process to ensure that the Data Manager and SKR Technical Team can regularly perform the updates as needed. It is possible that field measures of habitat quality described below (8.2.2. Field Evaluation of Habitat Quality) may be statistically compared with modeled habitat to further test and refine the habitat modeling methods.

Both before and after a more streamlined method for regularly updating the habitat models and maps is developed, they will be used to summarize annually the total acreage of suitable SKR habitat (possibly in multiple classes or strata, such as high, moderate, and low quality) rangewide and in each SKR ecoregion, including the acreage estimated to be occupied (using PAO methods described in Section 8.3.3). In addition, density estimates or indices produced by methods discussed in Section 8.3.4 may be intersected with occupied habitat polygons (or population units) to estimate total population sizes. Details of which metrics are most reliable and useful for status and trends estimates will be developed by the SKR Technical Team early in implementation.

## 8.2.2. Field Evaluation of Habitat Quality

Ideally, field-based habitat surveys should be completed at each trapping grid used for occupancy and discovery monitoring (Section 8.3). In addition to surveying for potential kangaroo rat sign, habitat variables should be recorded to assess correlations with modeled habitat values, test associations between habitat factors and SKR occupancy, and track habitat changes over time (e.g., following management actions or disturbances). Field protocols should be based on those used by USGS on MCB Camp Pendleton (Table 4 from Brehme et al. (2019)), refined as needed based on statistical analyses and discussions of the SKR Technical Team to make sure they are as cost effective and useful as possible. The intent should be to obtain meaningful measurements of soil, terrain, and vegetation conditions with minimal time investment.

**Table 4**. Field habitat survey form with variables to be recorded--from Brehme et al. (2019).

| Field Measure/ Covariate | Method | Data Fields | Purpose |
|---|---|---|---|
| **Landscape** | | | |
| Slope | clinometer | Percent slope | Habitat suitability |
| Aspect | compass | Degrees | Habitat suitability |
| Soil compaction | Lang penetrometer | PSI | Habitat suitability- burrow suitability, vegetation growth |
| Soil Texture | Laboratory Analysis- Brigham Young University | Sand (%)<br>Silt (%)<br>Clay (%) | Habitat suitability |
| Soil Conductivity | same as above | EC (dS/M) | Habitat suitability |
| Digital Photograph | Digital camera | Photo Number | Voucher |
| **Vegetation** | | | |
| Vegetation Type | From Zedler et al. 1997 | Veg list + Other (write-in) | Habitat suitability |
| Percent Cover- Open ground<br>Percent Cover- Annual Grasses<br>Percent Cover- Perennial Grasses<br>Percent Cover- Forbs<br>Percent Cover- Shrubs/ Trees | Visual estimate | Enter % | Habitat suitability |
| Dominant Species- Annual Grasses<br>Dominant Species- Perennial Grasses<br>Dominant Species- Forbs<br>Dominant Species- Shrubs/Trees | Visual Assessment | Species comprising >25% total cover in each vegetation layer (list) | Habitat suitability |
| **Kangaroo Rat Sign** | | | |
| Presence of Active Kangaroo Rat Sign | Search | Y/N | |
| **IF YES to above:** | | | |
| Type | Search | burrows (1.5" diam.) with apron, burrows (1.5" diam.) without apron, tracks, scat, dust bathing / cache sites, runways, none | Kangaroo Rat occupation |
| **Individual Rodent Sign Form** | | | |
| Date | | Automatic | |
| Type marked | | burrows (1.5" diam.) with apron, burrows (1.5" diam.) without apron, tracks, scat, dust bathing / cache sites, runways, none | Testing of temporal closure Assumption (see section "Supplements to ore Protocol" Brehme et al. 2006) |
| Location | GPS | Lat/Long | |
| Photo | Voucher | Y/ N (check off) | Voucher |
| Previously Marked? | Y/N | Pin flag, flag tape, other (choose one) | |
| Burrow Probe Used? | Y/N | Burrow empty, blocked, not able to negotiate turn, too narrow, too extensive | Check potential burrow for presence/ absence. Test utility of burrow probe. |
| Animal Found? | Y/N | Genus (species if possible) | |
| **Disturbance/ Other** | | | |
| Presence of gopher burrows | Search, Visual estimate | None/ Low/ High | Habitat suitability |
| Presence of squirrel burrows | Search, Visual estimate | None/ Low/ High | Habitat suitability |
| Presence of road/ firebreak | Search | Y/N (Type: dirt road, gravel road, paved road, firebreak)(Fill in distance for each: 0, 1-50, 51-200, >200 meters) | Habitat suitability/ dispersal |
| Recent Disturbance | Visual search & estimate | Vehicle tracks, footprints, hoofprints, fire, artillary (none, low or high- designation for each) | Management |

In addition, we recommend developing a rapid, visual habitat assessment method, such as a Relevé protocol -- for example, see "CDFW-CNPS Protocol for the Combined Vegetation Rapid Assessment and Relevé Field Form" (CDFW-CNPS 2019) -- that land managers can use to quickly assess habitat conditions in the field without the need for intensive data collection and statistical analysis.

# 8.3. SKR Occupancy Monitoring

Occupancy monitoring, or estimating the area of SKR-occupied habitat at a given time using **percent area occupied (PAO)** modeling techniques (MacKenzie and Reardon 2013), is the principal approach for tracking how well SKR populations are doing. The purpose of SKR occupancy monitoring is to establish and track the distribution of occupied SKR habitat rangewide and within each of the five SKR ecoregions delineated in Chapter 3.

We know that SKR do not fully occupy all population units delineated in Chapter 4 due to the species' natural patchiness and fine-scale habitat and population influences not captured by models. Simply summing the total area of population units would therefore surely overestimate SKR distribution and abundance to an unknown degree. A more defensible estimate of **percent area occupied (PAO)** requires systematic sampling of SKR presence and absence at a large number of sample sites distributed across the range and using occupancy modeling methods (MacKenzie and Reardon 2013), which adjust population estimates based on measured species detection probabilities. Occupancy estimates will therefore be calculated periodically (annually or every few years) from presence-absence sampling at a large number of standard grid locations following standard protocols, as described below.

## 8.3.1. Steps for Creating the Sampling Scheme

This document provides a foundation and guidance for developing a rangewide occupancy monitoring program, but the following steps need to be taken to finalize an implementable SKR occupancy monitoring scheme.

**Step 1. Refine the Spatial Sampling Units**.

This document uses the habitat suitability model to draft SKR **population units** as a spatial foundation for occupancy monitoring. However, these clusters of known occupied habitat patches should be refined to create a more defensible and implementable sampling design with a relatively high power to estimate species status and trends. Refinements would at least include further exploring the habitat value thresholds used to delineate population or sampling units, lumping or splitting draft units based on additional information (e.g., likely dispersal barriers), and overlaying them with land ownership and other spatial information that influence access and other practical matters.

The current draft population units were delineated by thresholding modeled habitat values into suitable and unsuitable categories using the MAXSS criterion (Liu et al. 2013, 2016). Although defensible for coarsely mapping contiguous patches of habitat within which SKR may be found, this method includes in the polygons large areas that are probably not occupied by SKR at finer scales (W. Spencer personal observations). Sample plots randomly sited within these polygons would consequently include many sites that are not actually occupied, thus reducing the statistical power of

PAO methods. We therefore recommend further exploring thresholding options for habitat values that would better discriminate between likely occupied vs. unoccupied habitat at finer resolution to delineate potential PAO sampling units. Similar to the sampling stratification scheme adopted by USGS on Marine Corps Base Camp Pendleton, this should allow for more efficient occupancy sampling and increased certainty in PAO estimates. Ideally, sampling theory indicates that the resulting sample units should be roughly 50% occupied (or more loosely, between 20% and 80%) across the range when sampled using a PAO sampling design.

**Step 2. Use Power Analysis to Allocate Sample Grids**

Once the spatial sampling units are refined, power analysis can be used to help determine the number of sampling sites (trapping grids) that best balances statistical goals of the monitoring program (e.g., the desired level of certainty in establishing population trends) with the practicalities of implementing the strategy in the field. This should be done interactively by an SKR Monitoring Subgroup with understanding of both the statistical design considerations and the practical field considerations. Guidance for the approach is presented in Section 8.3.2.

**Step 3. Detail the Sampling Program**

Based on results of steps 1 and 2, details of the sampling program should be provided in the monitoring plan, including establishing the precise sample grid locations, monitoring schedule, data collection and sharing protocols, personnel responsibilities, and other considerations. The SKR Technical Team or SKR Monitoring Subgroup should establish the grid points on a standardized digital map, with consideration of previously established grids, land access issues, independence of spatial samples, and other issues pertinent to the goals and assumptions of the PAO analysis.

**Step 4. Implement the Sampling Program, Analyze Results, and Revise as Needed**

The detailed sampling program should be tested in the field for 1 or 2 years. The data thus collected can replace the speculative parameter values used in the preliminary power analysis performed in Step 2. The results of the PAO analyses can then be used to revise the sampling program in an adaptive manner to ensure that the plan is practical, efficient, and meeting statistical goals.

## 8.3.2. Preliminary Power Analysis for Percent Area Occupied (PAO)

This section explores aspects of the PAO sampling design for consideration by the SKR Monitoring Subgroup based on Step 2 above in Section 8.3.1. It provides some rough estimates of the number of sample grids required to achieve monitoring goals, especially the ability to detect trends in SKR occupancy across the range. The analysis assumes that Step 1 has already occurred, such that sampling units have been refined to more precisely differentiate likely occupied vs unoccupied SKR habitat areas.

**Key Assumptions and Parameters**

PAO models require that the design and spatial scale of sample grids be standardized. Of particular importance are factors affecting the probability ($p$) of detecting (capturing) at least one SKR on a grid, and the probability ($\Psi$) that SKR are actually present in the sample areas. The probability of detection is influenced by the size of the area sampled by a trap array, as well as such factors as the season, duration (number of consecutive nights), and moon phase during trapping. The probability that SKR are present is partly influenced by the relative quality of the habitat in the sample area: if too much lower-quality habitat is included in potentially occupied habitat areas, many sample grids will likely have few if any captures, reducing the power to detect trends.

Ideally, the sampling scheme should be designed to produce a high probability of SKR capture (i.e., $p > 0.5$) and to ensure that roughly half of all grids are actually occupied by SKR (i.e., $\Psi \cong 0.5$). In practice, because occupancy will change over time and predictions cannot be perfect, roughly 20% to 80% of grids should be occupied during any sample period to obtain a reasonable power to detect SKR trends (i.e., $\Psi$ = 0.2 to 0.8). If instead $\Psi$ is too close to 0 (i.e., many grids are unoccupied) or 1.0 (all grids are occupied), the power to detect population changes will be weak and a larger number of sampling sites will be required.

**Preliminary Estimates of Number of Grids Needed**

Table 5 presents some preliminary estimates of the number of sample grids (S) required across the SKR range to achieve reasonable levels of precision (statistical certainty) that may be desired for the monitoring program. These estimates were made using a PAO “standard design” spreadsheet (which assumes all grids are trapped for the same number of nights) prepared by M. Pavelka of the US Fish and Wildlife Service (Appendix G: Design of Single Season Occupancy Studies). The spreadsheet allows one to evaluate how different assumptions (parameter values) will affect the power to detect population changes. These estimates can be used as preliminary guides for discussion by the SKR Monitoring Subgroup concerning tradeoffs between statistical power and practicalities of implementing the design. Once the Monitoring Subgroup creates an initial design, data collected during the first year or two of sampling can be used to test and refine the design.

The following assumptions were used to create Table 5:

- Traps are arrayed as 5 x 5 grids at ~15m inter-trap spacing (thus sampling a ~75m x 75m area) and are trapped for 3 consecutive nights (following one night of pre-baiting) while avoiding full-moon conditions.
- Detection probabilities are assumed to vary from $p$ = 0.6 to $p$ = 0.9 based on this design and estimates of $p$ from Brehme and Fisher (2009) on Marine Corps Base Camp Pendleton. That study estimated $p$ = 0.665 in Sep-Oct and ~1.0 in Nov-Dec using 10m intertrap spacing. We assume that the larger 15m spacing will result in similar or perhaps slightly higher $p$.
- The proportion of grids likely to be occupied by SKR are assumed to range from 0.2 to 0.8 (assuming the sample units are refined to achieve this using the thresholding analysis described above). Brehme and Fisher (2009) had expected, based on previous trapping results, occupancy rates, $\Psi$, of ~0.5 on their grids in high-quality SKR habitat, but they instead had very low estimates of $\Psi < 0.1$ on their standard 5 x 5 plots during 2005-6. However, they found much higher $\Psi$ ( ~0.5 to 0.7) on several larger plots (0.9 to 1.0 ha) previously established and trapped by S. Montgomery in known occupied areas.
- Finally, assume the monitoring program is designed to detect either a 30% or 50% change in SKR occupancy with 90% statistical confidence (i.e., the design has sufficient power to tell us

with 90% confidence that SKR occupancy has either increased or decreased by 30% or 50% between sample years). We assume that occupancy changes <30% are within the natural range of interannual SKR population fluctuations, but that changes >30% may signal a need for management responses. Using the 50% criterion would reduce the number of grids required, but at the loss of manager's ability to respond to changes until they become quite dramatic (>50%).

**Table 5**. The number of sample grids needed to detect a 30% or 50% change in SKR PAO assuming various proportions of sites occupied ($\Psi$ = 0.2 to 0.8) and probabilities of SKR detection ($p$ = 0.5 to 0.9) using 5 x 5 grids trapped for 3 consecutive nights each (K = 3).

| | | **Number of grids needed to detect change** | |
|---|---|---|---|
| $\Psi$ | ***p*** | **30%** | **50%** |
| 0.2 | 0.5 | 613 | 225 |
| | 0.7 | 488 | 179 |
| | 0.9 | 468 | 172 |
| 0.4 | 0.5 | 250 | 93 |
| | 0.7 | 187 | 70 |
| | 0.9 | 177 | 66 |
| 0.6 | 0.5 | 128 | 48 |
| | 0.7 | 87 | 33 |
| | 0.9 | 80 | 31 |
| 0.8 | 0.5 | 68 | 26 |
| | 0.7 | 36 | 15 |
| | 0.9 | 32 | 13 |

Evaluating the values in Table 5 reveals that under reasonable assumptions, roughly 100 to 300 sample grids may be adequate for detecting 30% changes in SKR occupancy, or roughly 50 to 150 grids for detecting 50% changes. For example, if occupancy is 40% and detection probability is 70%, then 187 grids would need to be sampled to detect a change of 30% magnitude, but only 70 grids to detect a 50% change. Thus there is a significant tradeoff between sampling intensity and the ability to detect SKR population changes that might indicate that changes in management are needed. This tradeoff must be weighed in the initial design of the sampling program.

Maximizing detection probability has the greatest influence on the number of grids necessary, but it is also important to refine the spatial sampling units to ensure high occupancy rates at sample grids. This emphasizes the need to focus sampling within the highest quality habitat areas. Further investigation of sampling options by the SKR Monitoring Subgroup should be used to hone in on a preferred design for the first year of two of PAO sampling. Once initial data have been collected, these hypothetical calculations can be replaced with calculations based on actual SKR data to refine the design in an adaptive manner.

### 8.3.3. Field Sampling Protocols

Once the sampling plan is fully defined, including maps marked with sampling sites, the following protocols will be used to assess and mark the sites in the field and collect SKR data at each site.

**Sign surveys, habitat assessment, and grid establishment**

Sample sites mapped during sampling design should be assessed and established in the field. This involves a thorough search for kangaroo rat signs (tracks, scats, trails, burrows) and habitat conditions on the ground to delineate likely occupied areas. For this, we recommend developing an app that allows biologists to walk the field with a digital map of modeled habitat value and to GPS in observed kangaroo rat signs (burrows and scats) as well as perceived boundaries of SKR-occupied areas. The results could then be uploaded to the SKR database system (9. Data Management Strategy). Grid corners should be marked in the field with flagging, stakes, or other methods, and the center point recorded with GPS, prior to trapping.

**Trapping Protocols**

Presence-absence trapping protocols for SKR have become relatively standardized over the years (Diffendorfer and Deutschman 2003, Brehme et al. 2006, Ortega 2007, 2011), but with some variations. We recommended starting with the following specifications (adapted from RCHCA protocols).

- Trapping should be performed once per sample year between September and December, depending somewhat on weather and vegetation conditions. Brehme and Fisher (2009) found a much higher probability of SKR detection (captures) during November-December than September-October in coastal San Diego County; however, weather differences between coastal and more inland SKR areas may dictate somewhat different sampling seasons in different ecoregions. As many grids as possible should be trapped simultaneously (at least within an ecoregion). Trapping should avoid periods within one week of full moon (or at least several nights from full moon) to maximize animal activity and capture probabilities, and should avoid periods of cool or moist weather that could endanger captured animals.

- Each sample site will be trapped for three consecutive nights, following one night of pre-baiting, using a 5 x 5 grid (25 traps) with roughly 15m inter-trap spacing (e.g., a 75 x 75m grid). *Note that RCHCA has used this 15m spacing, whereas USGS has been using 10m inter-trap spacing on military installations. We recommend the larger spacing to maximize capture probabilities for rangewide sampling. For continuity of the existing monitoring database in coastal San Diego County, the 10m spacing could be continued on some grids, at least for a transition period, so long as a sufficient number of grids use a standardized 15m spacing for the standardized rangewide estimates. The preliminary power analyses above suggest that fewer sample grids will be required on military installations to contribute to* *rangewide PAO estimates than the current >100 grids being sampled there. Thus, establishing some grids using 15m spacing while maintaining others at 10m spacing may fulfill both rangewide and military installation monitoring goals.*

- Traps will be folding aluminum Sherman (or similar) live traps (not open mesh traps), at least 12in long (i.e., Sherman XLK 3 x 3.75 x 12-in or Sherman XLF 4 x 4.5 x 15-in). If traps are <15-in long, the doors will be modified to prevent tail injury (either by rolling over 1-3 mm of edge at the top of the door or by using paper clips, pop rivets, or other modifications that moderate door closure).
- Bait will be sterilized (e.g., by microwave) bird seed or millet.
- Traps will be set and baited within 2 hours of sunset and checked once before midnight (but at least 4 hours after sunset), and once at dawn, and then closed during daylight.
- All captured kangaroo rats will be processed to record the following data: species, sex, weight (to nearest gram), age class (adult or juvenile), and reproductive condition (lactating, estrous, testicular) if observable. Animals will be marked with ear tags, Sharpie, or other approved marking method to facilitate recapture identification.
- Species ID must be made by a biologist experienced at differentiating SKR from DKR in hand. If there is any question about ID, the biologist will record diagnostic characters, including at least ear length, pre- and post-orbital skull width (using calipers), sharpness of the tail's black/white border and presence/absence of "grizzling" on the tail's dorsal surface, or other characters recommended by the SKR Technical Team.
- Hairs (or other tissue, if recommended by experts) will be plucked with clean tweezers or forceps from the rump and placed in an envelope labeled with species, location (site, grid/line, trap number), date, sex, and unique ID (an assigned number associated with field notes and GPS location) for genetic analysis. To collect hair samples, the handler should wear a fresh pair of latex gloves for each animal. Hair should be kept as dry as possible. Carefully pluck approximately 5-15 hairs with follicles attached, and immediately place into the envelope. DNA is present only in hair follicles, so avoid including shed hair or hairs lacking visible follicles. Use tape to seal each envelope. *Do not lick!* Samples should be refrigerated or frozen if possible, but can be stored at room temperature if necessary. Take a GPS coordinate at each trap location where a genetic sample is collected. Match it to the SKR unique ID or the grid and trap number. All captured animals will be released immediately at the point of capture following processing. Typically, animals should be held no longer than 5 minutes once removed from the trap.

### 8.3.4. Calculating Population Density Index

Following the methods tested on MCB Camp Pendleton (Brehme et al. 2019), a density index will be calculated for each habitat stratum (e.g., high, medium, low value) defined by thresholding modeled habitat values. The index will use the Huggins "closed capture" and "full closed capture with heterogeneity" models available in Program MARK (Huggins 1989, 1991). These models allow for missing data and the inclusion of covariates (e.g., sex, age, or day of capture) to model the probability of an individual's capture and recapture. From these conditional probabilities, an estimate of population size (N) can be calculated with confidence intervals on the sample grids. These grid estimates of N from the best fitting closed capture model--selecting the best model using the information-theoretic approach of Burnham and Anderson (2002)--can then be used to extrapolate densities across strata or across population units, and thus to estimate total population size within a region or rangewide. Annual results of these estimates can be used to track status and trends of the SKR population.

## 8.4. Genetic Monitoring

Genetic monitoring tracks status and trends in genetic diversity, relatedness, inbreeding, population structure, and **effective population size ($N_e$)**. These information sources are to be combined and reviewed on an ongoing basis to evaluate habitat fragmentation and population genetic health issues that may be addressed with management action and targeted for focused monitoring. Obtaining $N_e$ from genetic monitoring would be both more informative for management and monitoring purposes, and likely cheaper after an initial upfront cost, than estimates of population size based on capture-recapture or other methods of obtaining population size estimates. In addition, current genomic techniques can provide early detection of population declines.

Regular genetic monitoring should be conducted in tandem with occupancy sampling by collecting samples (hair) from trapped individuals and banking up to 50% of samples for future analyses. More details on techniques and sampling issues are provided in Appendix H, SKR Genetic Monitoring Proposal.

Protocol for kangaroo rat microsatellite genotyping and analysis, including calculating genetic diversity indices such as allelic richness, observed and expected heterozygosity, pairwise genetic differentiation, and effective population size, are described in detail in Shier and Navarro (2016) and Hendricks et al. (2020).

## 8.5. Calculating Population Status and Trends

Population status and trends will be assessed periodically (e.g., every 2 to 5 years) using the measures of SKR occupancy and density as calculated above, ideally within each population unit, SKR ecoregion, and rangewide. Annual estimates will be combined into a comprehensive status and trends report every 5 years. Given that genetic monitoring for effective population size proves feasible, $N_e$ should also be tracked on each population unit, ecoregion, and rangewide. It is possible that genetic monitoring may prove both more informative and more cost-effective than PAO and density estimates, in which case it may ultimately replace these methods.

## 8.6. Research Monitoring

Monitoring can be designed to answer specific research questions important to furthering SKR recovery, such as which of multiple management tools might be most effective in countering a threat. In particular, before-after/control-impact (BACI) monitoring designs (Balakrishnan et al. 2014) provide a useful approach for addressing many such questions.

### 8.6.1. BACI Design Research Questions

A BACI design measures a metric of interest (for example, population size or thatch density) before and after a management action (a treatment) in sample areas that experience the impact as well as on sites that do not (control sites). Multiple different treatment types can be tested, such as comparing plots managed with grazing versus fire versus mowing, as well as control plots with no treatment. Ideally, such experiments are performed with multiple replicates for statistical power, although in large-scale management situations this is often difficult. So long as the selected plots are reasonably similar in starting conditions, and the effects of treatments are relatively strong, large numbers of replicates may not be needed to reach confident conclusions.

A few examples of important research studies that could be set up with BACI designs include:

- **Habitat Features That Facilitate SKR Dispersal.** Non-invasive sampling methods (e.g., SKR track stations) could be used to compare alternative methods of improving habitat connectivity across non-suitable habitat areas, or the length of linear structures through non-suitable habitat (e.g., trails or dirt roads through chaparral) that SKR may use for dispersal.
- **Effectiveness of Road Crossing Structures**. Where improved roads (paved or gravel, as opposed to dirt) are thought to be impeding SKR movements between habitat areas, use of camera traps or other sampling methods could be used to document SKR use of potential road-crossing structures, such as bridges, culverts, overpasses or other features that may facilitate SKR road crossings. If improved structures are added, this should be monitored using a BACI design.
- **Comparison of Habitat Management Tools.** Where there remain questions about the most effective or cost-effective methods for improving habitat quality, alternative methods should be tested, as described above.

### 8.6.2. Population Genetic Structure

A wide array of important hypotheses about population and genetic structure (including interbreeding and gene flow patterns) could be answered with modern genomic techniques. A full review of possibilities is beyond this current planning document, but given that genetic monitoring commences, the SKR Technical Team should evaluate priority hypotheses for testing. Clear examples are discussed throughout this document, including whether dispersal and gene flow is currently happening between the coastal San Diego County SKR populations and others, and the degree of isolation and gene flow among the inland San Diego County populations (Ramona, Guejito, and Warner Basin) as well as their relation to populations in Riverside County. Likewise, to what degree any currently unique gene pools represent the effects of local adaptation versus nonadaptive genetic drift, and whether “genetic rescue” or augmentation is a management priority for any populations, especially small and isolated ones like the Ramona Grasslands.

# 9. Data Management Strategy

Although a significant amount of monitoring data is already being collected by SKR managers (Appendix F: Existing SKR Monitoring Efforts), there is currently no standardization or central compilation of the data for rangewide purposes. We recommend establishing a set of standard specifications for data collection, formatting, and quality-checking, and a centralized data management system to facilitate analyses of SKR status and trends.

In addition to providing data for tracking SKR habitat and populations across the range, a fully-implemented SKR Data Management Strategy will provide standardized data to researchers to generate and test hypotheses pertinent to SKR conservation, such as how regional differences in climate may affect SKR populations, the effectiveness of alternative management methods, or how dispersal between population units may affect genetic structure and population viability. Standardizing terminology between reserves and researchers can help minimize errors caused by misinterpretation of the data.

Systematic updating of habitat models, population units, sampling areas, and other attributes is essential to tracking rangewide and regional changes in SKR status and trends as part of the Adaptive Management Cycle (Figure 11). These updates will then be used to make decisions about SKR conservation priorities, such as where and how to enhance populations, restore habitat, adjust monitoring, and so forth. The updated knowledge will also inform where specific research questions can be addressed with additional monitoring data.

## 9.1. Elements of a Rangewide SKR Data Management Strategy

Key elements of a Rangewide SKR Data Management Strategy are: (1) the organizational roles and responsibilities for data collection, QA/QC, reporting, aggregation, and analysis; (2) the standards for data fields (entities), database structure (schema), terminology (attributes), and reporting instructions; and (3) software tools to facilitate all of these elements.

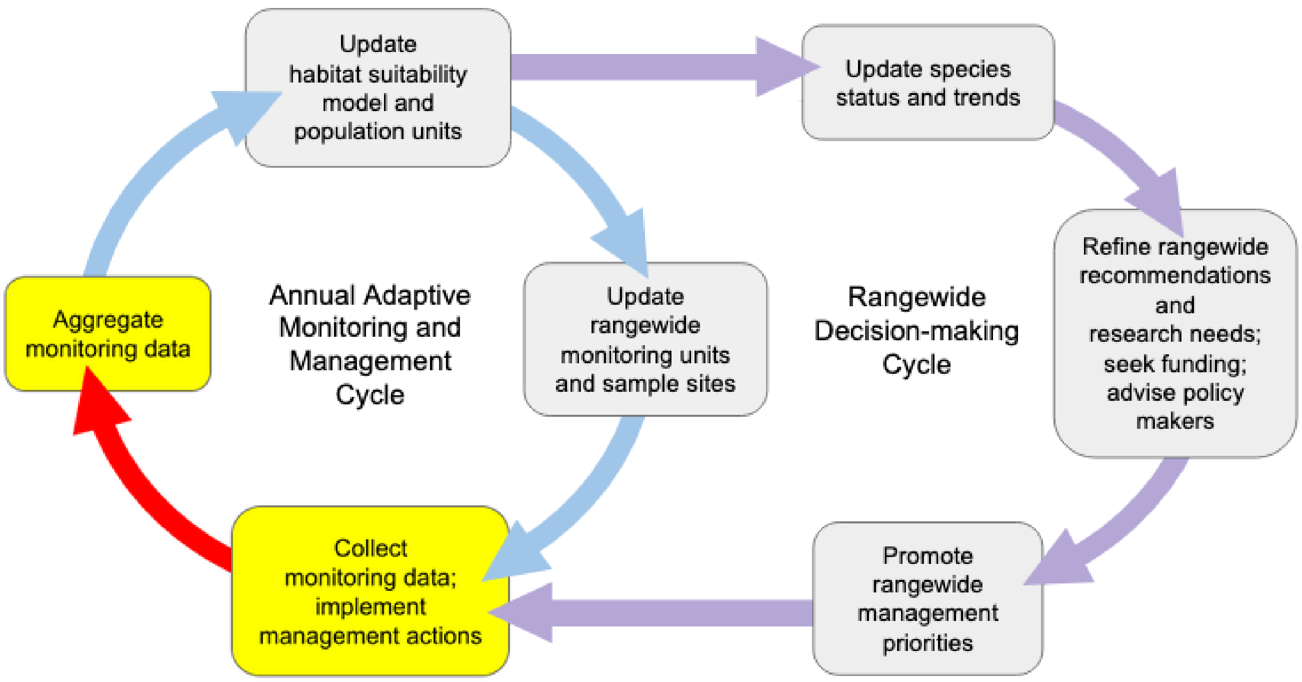


**Figure 11**. SKR Adaptive Management Cycle highlighting the steps supported by the Rangewide SKR Data Management Strategy.

### 9.1.1. Responsibilities and Oversight

Implementing this coordinated Data Management Strategy will require the designation of roles and responsibilities. We recommend these be determined as part of the Coordination Structure early in the Implementation Phase upon finalization of the Rangewide Monitoring Strategy.

The Coordination Structure must lay out clear data management roles, responsibilities, and oversight to ensure that monitoring data can be efficiently aggregated to support annual assessments of the species' status and trends and timely updating of monitoring, management, and research priorities. Reserve managers will be responsible for implementing the standardized rangewide monitoring protocols and reporting their data to the **Data Manager**. The Data Manager will combine, quality check, and add data to the SKR Monitoring Database and make it available to the **SKR Technical Team**, which will use the new data to update the habitat suitability model and evaluate SKR status and trends. The organization that takes the role of Data Manager will be determined by the **SKR Implementation Team** with development of the Coordination Structure.

### 9.1.2. Data Collection Protocols and Standards

To contribute to the rangewide SKR Monitoring Database, the field data collector (the reserve manager or contracted field biologist) will need the following:

- Standard population and habitat monitoring protocols from the SKR Monitoring Plan.
- Data content and structure standards for population and habitat data: Content standards are the list of fields and the instructions for filling them out (also known as a data dictionary). Data structure standards describe the exact way the fields are contained and related to each other in a database (also known as a relational database schema). These can be encoded into a data collection tool such as the Collector App to make them easy to use.
- Quality assurance and control instructions. Successful data aggregation requires completeness, consistency, and documentation of the input datasets. Data collectors will need clear instructions for performing data QA/QC before forwarding data to the Data Manager responsible for aggregating the data into the central database.
- Protocol for reporting data to the Data Manager(s) for inclusion in the SKR Monitoring Database.

To implement the SKR Data Management Plan these protocols and standards must be developed based on the finalized SKR Monitoring Protocol, and vetted and tested by the SKR Technical Team in the implementation phase of this effort.

### 9.1.3. Data Collection and Reporting Software Tools

We recommend developing software applications to automate and simplify field data collection and reporting. These could include (1) a version of the RCHCA Collector App with a digital form for SKR population and habitat field data collection, and (2) a web-based system for uploading the data to the SKR Monitoring Database, conducting QA/QC, and visualizing the data in dynamic maps. Such apps will help ensure easy, consistent application of the standards and protocols and provide motivation for completing the process each year.

We also recommend developing a digital mapping app that allows field biologists to GPS in kangaroo rat burrows and other signs and possibly to delineate edges of occupied vs unoccupied habitat areas for use in locating PAO sampling grids in the field. The app should display the latest version of the SKR habitat quality map (thresholded into multiple quality classes) to aid the biologists focus their observations in the most likely areas to support SKR, and allow them to map their observations and suggest refinements to the habitat delineations in the field.

# 10. Coordination Structure

We recommend that the current SKR Working Group begin by setting up a Coordination Structure (Figure 12) with a coordinating body to oversee Plan implementation. Below we suggest a preliminary framework for such a Coordination Structure, which should be refined immediately upon initiating Plan implementation. The Coordination Structure should clearly describe roles and responsibilities of each participating agency and how they will coordinate communications, meetings, workflow for the SKR Adaptive Management Cycle, and decision-making.

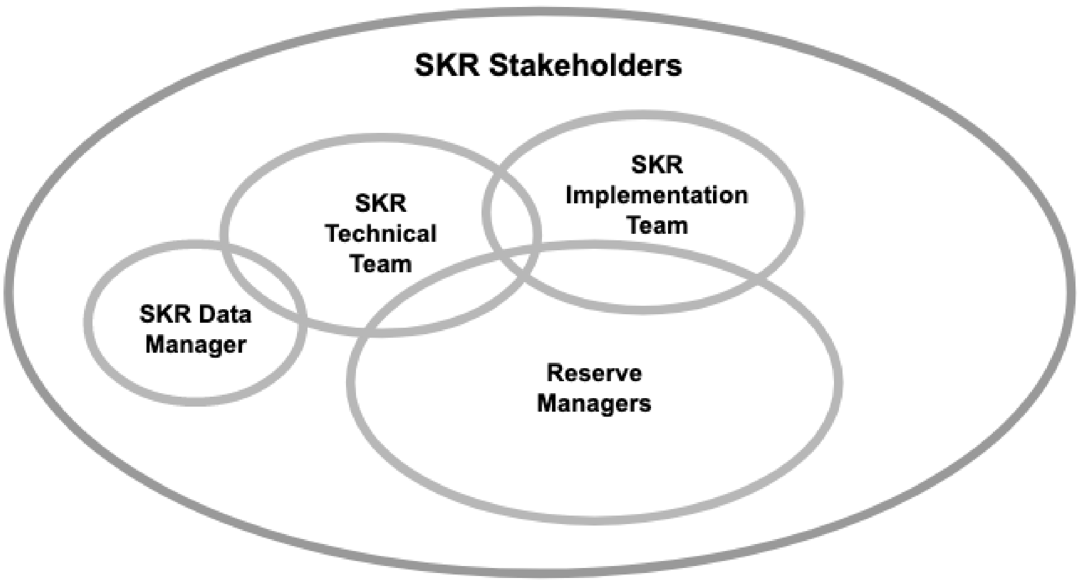


**Figure 12.** The Coordination Structure consists of the teams that support the SKR Adaptive Management Cycle. Teams are composed of members of the larger SKR Stakeholder Group. Overlapping team memberships facilitate collaborations and information sharing.

We tentatively recommend the following team roles to guide Plan implementation via updating of scientific knowledge and the exchange of information required for the SKR Adaptive Management Cycle, guiding management decisions, engaging stakeholders, and raising necessary funds. The timing and flow of the information and task performance should be managed to facilitate the Adaptive Management Program.

**An SKR Implementation Team** will oversee and coordinate Plan implementation to further rangewide SKR conservation goals. The team will coordinate reporting of monitoring and research data, prioritize and provide funding for management, monitoring, and research tasks, and provide overall guidance and leadership for actions having rangewide SKR conservation implications. The Implementation Team will be advised by the **SKR Technical Team** (species experts, database experts, and reserve managers) and consider input from the **SKR Stakeholders** (others with an interest in SKR conservation). The Implementation Team will work to avoid unnecessary competition for resources, encourage pooling of resources to address critical issues, and consult with other agencies as needed for logistical support (e.g., CalFire).

The **SKR Technical Team** will comprise a suite of SKR experts, database and analysis experts, and reserve managers that review previous years' monitoring data and research, update the habitat suitability model, biogeographic maps, population units, monitoring sample allocation, and other technical tasks, and make recommendations to the Implementation Team for each year's monitoring and management actions as part of the adaptive management cycle. The Technical Team will regularly update and review SKR status and trends, as well as the effects and effectiveness of management actions. The Technical Team may designate ad hoc working groups, such as a Monitoring Subgroup or Database Subgroup to tackle specific technical issues.

A larger body of **SKR Stakeholders**--including interested agencies, policy makers, conservation organizations, researchers, and land managers--will consult in two-way communication with the Coordination and Technical teams to keep them informed of emerging SKR issues and to learn from the adaptive management program to inform their own roles in SKR conservation and land management decisions.

**Reserve Managers** are responsible for conducting monitoring, contributing their data to the SKR Data Manager for aggregation, and implementing recommended management actions. They will be encouraged to participate in discussions with the Implementation Team to provide their lessons learned for refining the recommended management actions.

A designated **Data Manager** will be responsible for aggregating and curating the monitoring data from the reserves and making it available to the Technical Team for use in updating the Habitat Model and population units, as well as to the Reserve Managers for their uses.

Together these groups implement the SKR Adaptive Management Cycle, all playing important roles for moving information through the cycle to inform SKR management with the latest science and insights from the field. See Figure 13 for Coordination Groups' roles in the Adaptive Management Cycle.

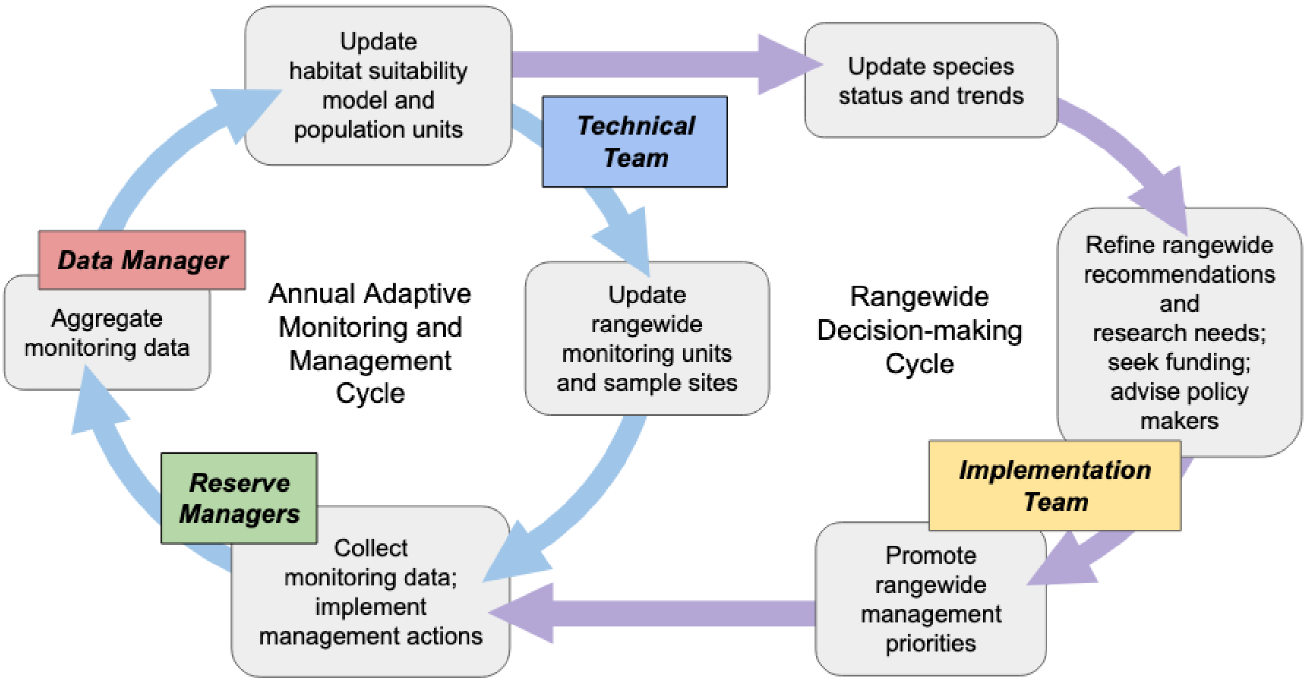


**Figure 13.** Coordination groups and their roles in the SKR Adaptive Management Cycle.

# 11. Recommendations & Next Steps

Based on information contained in this document and discussions of the SKR Working Group, we summarize the following recommendations for tasks to be carried out early in Plan implementation. They include refining the database and map of SKR reserve status and SKR occupancy; refining the SKR habitat and population units to better define the spatial sampling units for monitoring; better standardizing field monitoring protocols; fleshing out details of the data management system, including settling on the standardized set of data fields and formats to be used by all parties; and developing streamlined methods for regularly updating the habitat quality map, population occupancy and density estimates, and analyzing rangewide SKR status and trends. We also recommend seeking funding for and designing and implementing some important research studies to improve our understanding of which management actions and where will most benefit SKR conservation and recovery.

## 11.1. SKR Reserve and Locality Information

Information about SKR reserves and localities that might support the species but where their status is unknown should be refined and updated in text and on the biogeographic map as it becomes available. Section 5.1 of this document describing SKR Biogeography lists reserves and other places that may support SKR habitat and populations, but the list and associated maps are incomplete. For example, Kabian Park, which is managed by the Riverside County Parks District, supports predicted suitable SKR habitat, and SKR or kangaroo rat signs have been detected nearby, but to our knowledge surveys for the species have not been conducted on the park. It would be helpful to document whether or not SKR currently occupy this and other areas with predicted suitable habitat to determine if management and monitoring may benefit the SKR metapopulation. In some cases, even small protected areas may contribute to SKR population connectivity and overall metapopulation sustainability, so a more comprehensive documentation and map of the possibilities would be helpful.

## 11.2. SKR Habitat, Population, and Sampling Units

The draft habitat and population units developed in Chapter 4 should be refined early in Plan implementation, prior to finalizing the monitoring sampling allocations, and periodically updated throughout implementation (ideally annually or at least every 5 years). This would entail at least the following tasks:

1) Refine the SKR locality database to account for missing data, include recent (post-2018) localities, clearly indicate definitive SKR observations vs sign-only observations (which may be DKR), account for any known recent extirpations, and perhaps other refinements. Periodic updates should routinely account for local colonization or extinction events based on the occupancy monitoring results.

2) Explore alternative thresholds for dividing potential habitat into suitable vs unsuitable habitat areas, or high, medium, or low quality habitats to refine the delineation of habitat and population units. This is especially important for designating the sample units to be included in

PAO sampling (Section 8.3), for which it is best to delineate potentially occupied habitat units that have roughly 50% probability of being occupied (or between about 20% and 80%) for the greatest power in estimating species status and trends.

3) Split habitat units where there are obvious dispersal barriers (e.g., major roads or canals) crossing them, or lump units where genetics or other evidence demonstrate that habitat patches >200 m apart are functioning to support an interbreeding subpopulation.

4) As dispersal barriers may be removed or mitigated during Plan implementation (e.g., with road-crossing structures or dispersal corridor creation) population units may be combined if monitoring demonstrates that the improvements are successful in facilitating SKR movements such that previously independent population units begin functioning as one.

## 11.3. Monitoring Plan

This document provides a framework and guidance for developing a fully implementable monitoring plan, but additional analyses and discussions are required to complete that. Based on the strategy laid out in this document and discussions by the SKR Technical Team, a detailed SKR Monitoring Plan must be developed to ensure that it is fully implementable, which must specify exact sampling sites (grids), sampling schedules, and responsible parties, finalize the data fields to be collected, specify field habitat measures to be used as covariates in occupancy and density estimates, and related issues.

The sampling design should be based on statistical power analyses as described in Section 8.3.2 to ensure it will provide adequate certainty for status and trend updates, without requiring unrealistic effort and costs. Together with the Data Management recommendations below, the monitoring plan should be sufficiently documented such that reserve managers and other responsible entities can adopt and implement the monitoring plan, including standardized protocols, data collection and reporting standards, etc. For references and a starting point, see Appendix F: Existing SKR Monitoring Efforts and Appendix G: Design of Single Season Occupancy Studies.

## 11.4. Data Management

The SKR Rangewide Data Management Strategy should be implemented by taking the next steps together with the SKR Implementation Team:

1) Identify the organization that will serve as Data Manager.

2) Establish content and structure standards for the core set of data to be collected using the finalized rangewide habitat and population monitoring protocols.

3) Develop instructions for data QA/QC and reporting to the Data Manager. The data can be collected by the reserve managers using their medium of choice (paper forms or a digital data collection mechanism such as the RCHCA's "Collector App"), but the core data should be reported using a standard digital format, schema, and data dictionary so that it may be

aggregated into one database.

4) Develop forms and digital software applications to automate the process of data collection, analysis, QA/QC, and reporting as much as possible.

5) Establish a website where all of the above-mentioned information and resources can be found in one place, and where reserve managers can contact a person with their questions. CBI has created a SKR Rangewide Management & Monitoring Plan Map and Data Gallery on Data Basin where the resources described in this Plan can be found (https://databasin.org/galleries/f4e9f7ccfe744367bbe8440d858e92ad/).

## 11.5. Streamlining Updates of SKR Habitat, Occupancy, and Population Status and Trends

This Plan proposes to use the updateable habitat model as a foundation for tracking changes in habitat quality and distribution and SKR population distribution and size in order to regularly update the assessment of species status and trends. However, the process for updating the variables derived from satellite imagery, re-running habitat models, and using them to update maps of habitat quality and population occupancy is highly technical. We recommend a small committee of modeling, programming, and GIS experts to develop a streamlined and perhaps automated method for performing these updates, along with a training and technology transfer process to ensure that the Data Manager and SKR Technical Team can regularly perform the updates as needed.

## 11.6. Research Studies

We recommend addressing the following research issues early in Plan implementation. To the degree that these recommended research studies cannot be funded by existing monitoring and management budgets, the SKR Implementation and Technical Teams should seek grants or other funds for them.

1) **Population Modeling**. We recommend developing a spatially explicit metapopulation dynamic model (e.g., using HEXSIM; Shumaker and Brookes 2018) to investigate where management interventions might be most necessary and effective. The model would integrate data on habitat quality, population distribution and abundance, demographic processes (birth, death, dispersal), and potentially genetic diversity, to project the likely effects of various management scenarios (e.g., habitat improvements, barrier mitigation, SKR reintroductions) on population dynamics and metapopulation viability.

2) **Effectiveness of Connectivity Improvements**. The ability of SKR to disperse between habitat patches and population units is critical to long-term metapopulation function and sustainability, and mitigating **dispersal barriers** and **filters** should be a management priority. Although SKR are known to disperse along such features as dirt roads and trails, little is known about factors influencing successful dispersal or how best to increase the ease and safety of dispersal across such features as paved or gravel roads, housing developments, agricultural fields, or other barriers and filters. We recommend further research on the efficacy

of potential crossing structures to improve population connectivity, such as use of culverts and perhaps SKR fencing to funnel dispersers through safe passageways.

3) **Population Genetics**. Studying the SKR Biogeographic Map and results of recent and ongoing population analyses suggest some important hypotheses to test to better inform management actions that could improve gene flow amongst subpopulations (e.g., via improving SKR movement potential or using SKR translocations to augment local gene pools). Of particular interest is further investigating the degree of genetic isolation and gene flow amongst the southern populations in San Diego County, including between the Ramona Grasslands, Rancho Guejito, Warner Basin, and perhaps other habitat units. Nested within this question is whether the two subpopulations currently delineated on Rancho Guejito are functionally connected as one interbreeding population, or rather function as two subpopulations with little or no gene flow between them. Likewise, further understanding the degree of isolation and gene flow within the coastal San Diego region and from that to other regions would be beneficial. Although difficult to study, it would be useful to understand to what degree genetic differences between populations are the result of genetic drift, or might reflect local adaptation via natural selection. Discussion between the SKR Technical Team and population geneticists could help refine the hypotheses, determine which are feasible to test with modern genetic techniques, and design appropriate studies.

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