Connecting Valley and Foothill Habitats to Higher Elevations in Sequoia and Kings Canyon National Parks Through Corridor Mapping

FINAL REPORT

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Abstract

The San Joaquin Valley of California is a highly agricultural area that has lost most of its natural habitat due to urbanization and agricultural development. The remaining habitat is highly fragmented. With the added pressures of climate change, species that reside in these habitat fragments are even more vulnerable to extirpation. Sequoia and Kings Canyon National Parks can provide relief to nearby San Joaquin Valley and foothill habitats due to their large elevation gradient, which could allow species to adapt to warming climate by moving up in elevation to cooler temperatures. However, many of the isolated species in the Valley do not currently have a safe pathway from habitat fragments like Dry Creek and Kaweah Oaks Preserves to the parks. By developing a least cost path from evaluating suitable conditions for six generalist species – the western fence lizard, western pond turtle, gopher snake, mule deer, valley oak, and black backed woodpecker – in the Kaweah Watershed, potential corridors were found for each species individually. These paths were overlaid on MaxEnt habitat probability maps for present climate conditions and two future climate predictions from the GFDL 2.1 A2 scenario to narrow down the potential paths to those that contain the most livable habitat. These individual species pathways were analyzed to prioritize those with the largest intersection, ultimately resulting in maps of potential general corridors that Sequoia and Kings Canyon National Parks can evaluate for potential protection or rehabilitation.

Introduction

The San Joaquin Valley in the southern end of the Central Valley of California has experienced habitat loss and fragmentation, primarily due to agricultural development, resulting in a 95% decrease in overall natural habitat (Purkey 2001; Matocq 2012). As climate change heightens the effects of fragmentation in the Valley, thousands of species at risk of extirpation will be forced to migrate or adapt to altered conditions (IPCC 2014). Allowing affected species to move freely between neighboring habitats can help them survive while further action is taken to mitigate anthropogenic disturbances. Neighboring the San Joaquin Valley are Sequoia and Kings Canyon National Parks, also known as “SEKI,” which serve as a refuge for wildlife and biodiversity (National Park Service 2013). By connecting foothill and valley habitats outside the parks to habitat inside the parks through a series of wildlife corridors, native species may have the opportunity to migrate to safety in higher elevations as their current habitat becomes increasingly fragmented, degraded, or destroyed by climate change and other anthropogenic influences.

This study presents an analysis of the quality and distribution of current habitat in the valley and foothill regions surrounding the southwest border of SEKI as well as explores the long-term impacts of climate change on the potential spatial distribution of six focal species to assess viable wildlife corridor options. Mapping potential wildlife corridors is an important first step in mitigating the impacts of fragmentation on biodiversity by connecting at-risk fragmented populations in the Kaweah watershed to the relative security of SEKI.

Background

THE SAN JOAQUIN VALLEY

Historic Land Use

The San Joaquin Valley is a 43,000 square-kilometer basin located in the lower two-thirds of California's Central Valley (Figure 1). It is one of the largest agriculture centers in California, generating 66.1% of the total agricultural economy of California in 2011 (Ross 2013). The Valley is classified as a perennial grassland and is located in a mediterranean climate (Huber 2011). Most of the native species originally in the Valley have been replaced by hardier, European species (Wester 1981). In 1850, before anthropogenic activities re-engineered the landscape, the Valley was comprised largely of grasslands (51%), wetlands, water, or riparian habitat (31%), alkali scrub (16%), and foothill hardwood or chaparral (2%) (Thorne 2014). However, beginning as early as the 1830's water intensive farming techniques and cattle grazing among other activities have since substantially transformed the natural landscape. Only 4% of the San Joaquin Valley remains unaltered (Haslam 1993; Wester 1981) and today the landscape of the San Joaquin Valley is comprised of agriculture (61.4%), grasslands (28.3%), urban (5.8%), wetlands, water, or riparian habitat (2.4%), and foothill hardwood, chaparral, or alkali scrub (2.1%) (Thorne 2014).

Historically, the southern end of the Valley was dominated by Tulare Lake, a seasonal, freshwater lake that served as a water source for wildlife and supported local fisheries. In the early 19th Century it was the largest freshwater lake in the United States west of the Mississippi River, but after the diversion of its tributaries in 1870 to agriculture in the lower valley, evaporation caused the salinity of Tulare Lake to rise too high to support commercial fishing, and the dried lakebed was converted to agricultural land (Haslam 1993). The former lakebed is now indistinguishable from the rest of the San Joaquin Valley (*Id*).

Much of the agricultural production in the Valley today, which persists despite the Valley's relatively dry natural climate, was made possible by a 1935 decision by the U.S. Bureau of Reclamation to build the Central Valley Project (CVP). The CVP is a system of water storage reservoirs and canals that divert more than 7,000,000 acre-feet of water per year from Northern California to the Central Valley (USBR 2017). The CVP provided relief from the prior decades of groundwater overdraft across the Valley by carrying Sierra snowmelt and water from the Sacramento and San Joaquin Rivers to irrigate 1.5 to 3 million acres of the drier portion of the Valley (Reisner 1993). The mass-scale diversion of water for agricultural development has resulted in the diking, draining, or filling of 95% of the Valley's historic wetlands leaving the remaining critical riparian habitat severely fragmented and degraded (USFWS 2012).

Current Habitat

Most remaining intact natural habitat is located in federally protected land which comprises 26.5% of the Valley's total area, including SEKI. Natural habitat outside of these protected areas has decreased significantly, resulting in a reduction of total habitat area and isolation of habitat fragments (USFWS 2012) as well as changes to historic habitat of numerous species. The woodrat, for example, has only one or two areas left of suitable habitat due to the damage of riparian habitats (Matocq 2012). Fragmentation, the separation of contiguous habitat into isolated patches, intensifies susceptibility to environmental changes and to edge effect, the effect of an abrupt transition between two adjoining ecological communities, both of which contribute to local extinctions and loss of biodiversity. The main contributors to habitat loss in the Valley are water diversion, damming, grazing, and agriculture development (*Id*).

Biodiversity

After decades of intense water use and high conversion rates of natural land to agriculture and urbanization, the foothill and valley ecosystems of the San Joaquin Valley are under immense stress (Hanak 2017). Currently, habitat loss in the San Joaquin Valley has contributed to the listing of 66 species as threatened or endangered by the state or federal government (Thorne 2014). As fragments become smaller, they support smaller population densities with less genetic diversity making it more difficult for species to survive and adapt to increasing environmental pressures (Lande & Shannon 1996). A 1997 study in Southern California, for example, surveyed 25 fragments of coastal sage scrub and chaparral habitats and found that 13 of 25 fragments did not contain a population of native rodents, and that the fragments that did contain populations had lower densities than equivalently sized areas contained in large unfragmented habitat (Bolger et al. 1997). From 1984 to 2010, 141,000 acres of non-grazing farmland in the San Joaquin Valley was transformed by urban development (Thorne 2014). As the population of the San Joaquin Valley is expected to grow to 9.5 million people by 2050 compared to 4 million people in 2010, urban development and land use change will continue to stress the landscape of the Valley (Connell-Buck 2011). Future habitat loss will occur primarily in grasslands which are expected to decline by as much as a 37% in the San Joaquin Valley due to development by 2100 compared to 2010 conditions (Byrd 2015). These highly ecologically damaged areas in the Valley will be the most susceptible to climate change (Huber 2011).

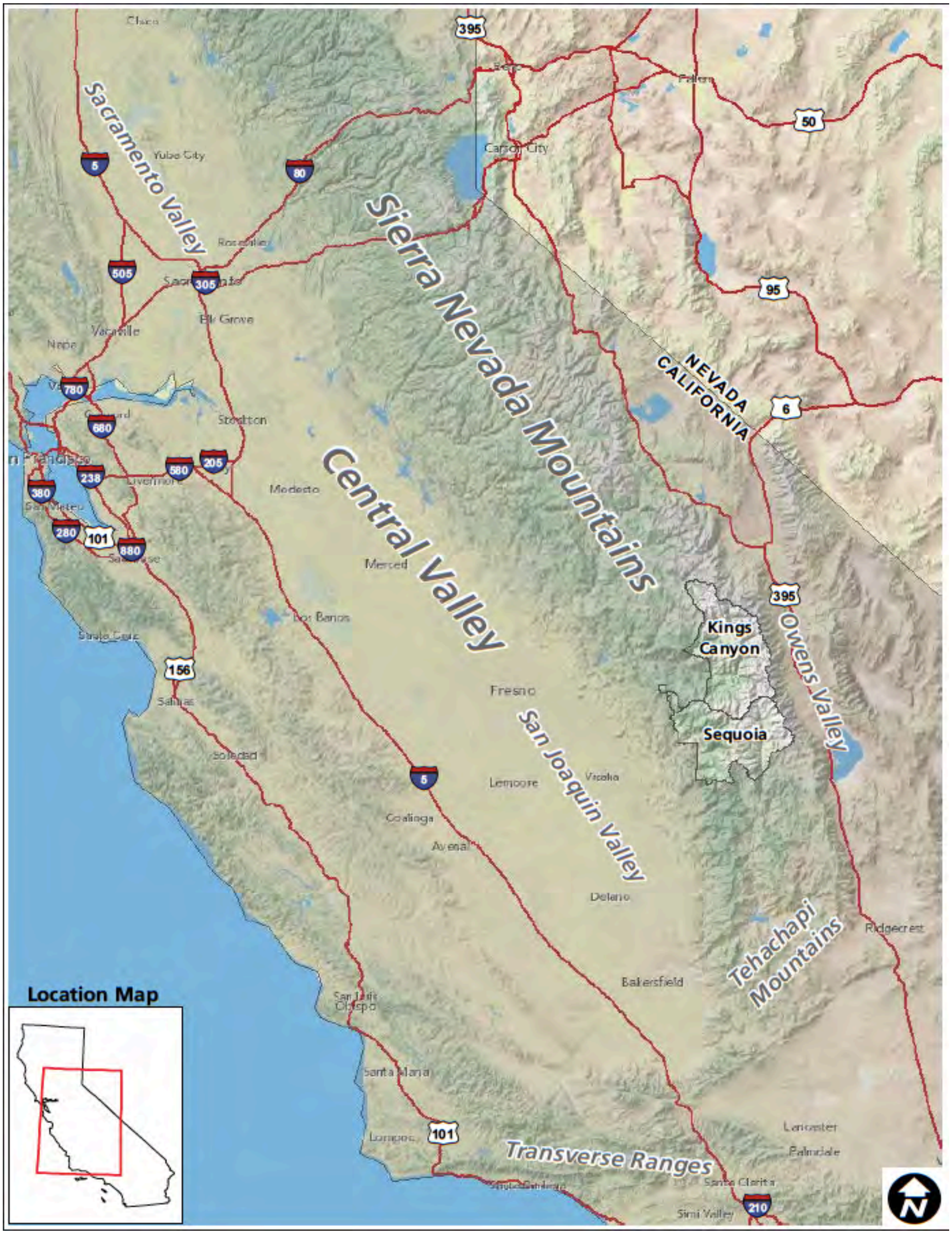

__Figure 1:__ Regional overview map of the Central Valley (National Park Service 2013)

SEQUOIA AND KINGS CANYON NATIONAL PARKS

Sequoia and Kings Canyon National Parks span from the foothills of the San Joaquin Valley to the crest of the Sierra Nevada Mountains. In total, SEKI cover approximately 865,964 acres of land (National Park Service 2013). The wide range of ecological diversity protected within the parks serves as core habitat to Sierra Nevada wildlife, which includes 204 species of birds, 83 species of mammals, 24 species of reptiles, 12 species of amphibians, and 8 species of fish (*Id*). The parks also contain numerous bodies of water, including an estimated 3,365 lakes and ponds, and 2,600 miles of rivers and streams, which provide habitat for aquatic species and promote vegetation growth critical for sustaining park wildlife (Boiano et al. 2005). Given its strong elevational gradient and large amount of undeveloped habitat, SEKI has the potential to serve as a climate change refuge for species currently isolated in in the Valley's habitat fragments.

Ecological Zones

SEKI connect to the foothill vegetation of the San Joaquin Valley primarily on the southwest border of Sequoia National Park (Figure 2). This region in the parks is classified as low elevation hardwood and chaparral, the smallest ecological zone in the parks, constituting only 6% of the parks' area. Also referred to as the foothills, this region is located below elevations of 5,000 feet. Precipitation in this region of the park is variable with dry summers and wet winters averaging 26 inches of annual rainfall (National Park Service 2007). As a result, species have adapted to the prevalent fires and drought conditions (Baron 2008). The predominant plant communities in this ecosystem include oak woodland, blue oak savannah, and chaparral (Sydoriak et al. 2013).

The montane zone is the largest ecological zone of the parks, extending across 46% of their total area. The montane zone is located in the western region of the parks between elevations of 5,000 and 9,000 feet (Sydoriak et al. 2013). Despite receiving far more precipitation than the foothills, with an annual average rainfall of 45 inches, fire is prevalent in this region and aids in conifer seed dispersal (National Park Service 2007; Hartesveldt 1967). Giant sequoia groves are a significant plant community in this ecosystem (Harvey et al. 1980). However, due to fire suppression policies, they have had difficulty reproducing in their original habitat (Miller 2009). The other vegetation in this zone is described as a mixed-conifer forest, with diverse forests of ponderosa pine, white fir, red fir, and lodgepole pine respectively as the elevation increases (Rundel et al. 1988).

Located in the eastern region of SEKI towards the peaks of the Sierra Nevada Mountains are the subalpine and alpine zones. Cumulatively, these zones occupy 48% of the parks' total area (Sydoriak et al. 2013). These regions occur in the High Sierras at elevations greater than 9,000 feet (*Id*). Subalpine forests of whitebark pine and foxtail pine dominate the landscape between 9,000 and 11,000 feet (Fites-Kaufman 2007). Above 11,000 feet, in the alpine region, trees are rare and the vegetation shifts to grass and flowering herbaceous species (*Id*). Very few plants are adapted to grow in such extreme conditions and most wildlife found here is transient (Wathen et al. 2014). Temperatures in these regions are extremely cold and precipitation primarily comes in the form of snow (National Park Service 2007). Snowpack in these regions serves as a natural storage system which slowly releases critical water supplies to the surrounding ecosystems during the dry months of spring and summer (Boiano et al. 2005).

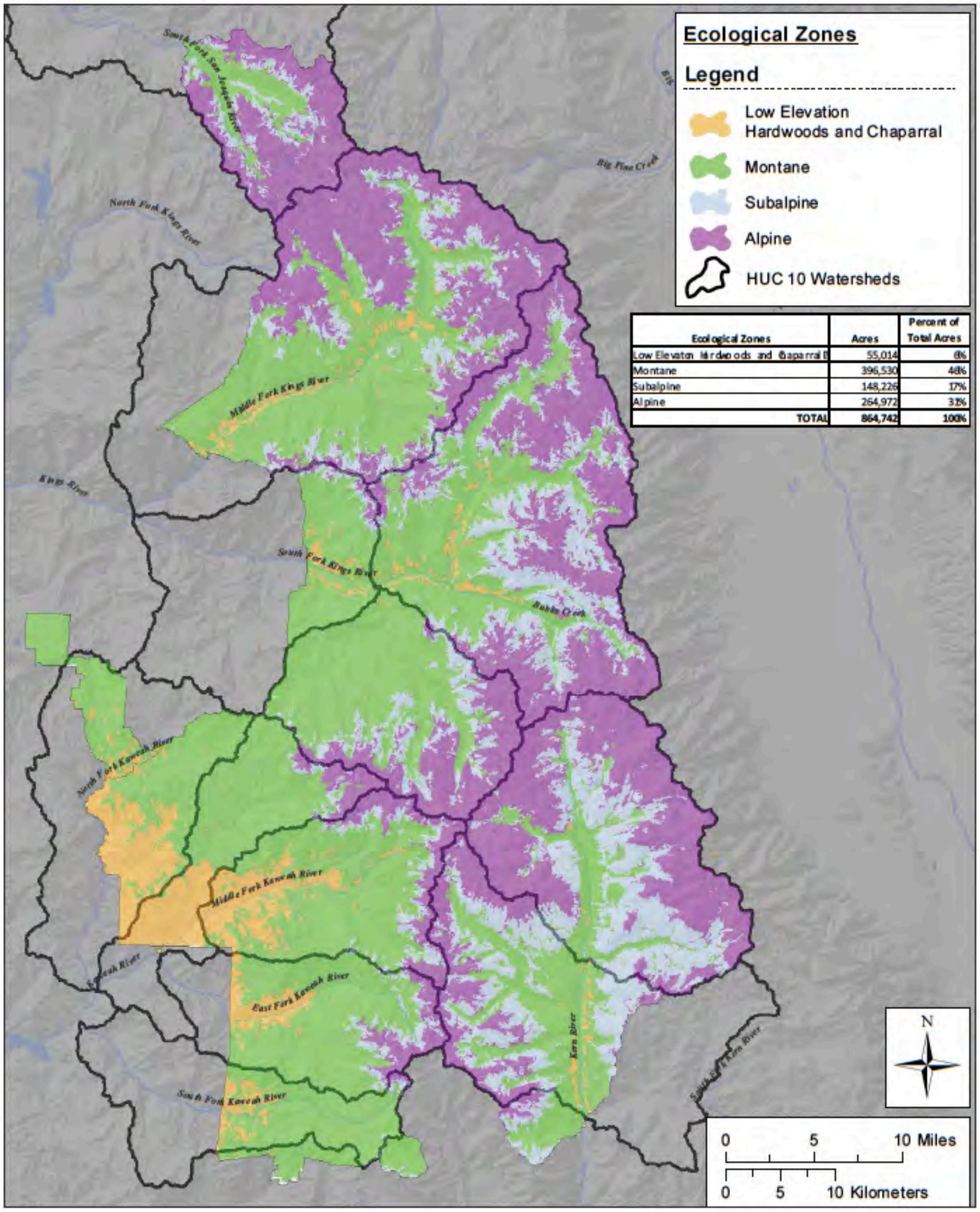

Figure 2: *Map of the ecological zones located in SEKI (Sydoriak et al. 2013)*

CLIMATE CHANGE

Changes in Earth's climate caused by the compounding effects of anthropogenic actions are likely to have a severe impact on vulnerable ecosystems in the near future. Climate change could have drastic, irreversible, and unpredictable global effects on biodiversity and ecological function as factors including wind, moisture, precipitation and temperature fluctuate abnormally (USEPA 2016). Valley and foothill communities in the San Joaquin Valley are already significantly fragmented, which will likely intensify as climate continues to change. Access to Sequoia and Kings Canyon National Parks would allow species from these fragments to take advantage of the parks' elevation gradient and areas of cooler climate.

Climate Impact Models

Climate models apply mathematical equations to represent relevant processes on earth, such as fluctuations in solar energy, volcanic activity, changing greenhouse gas concentrations, aerosols, and land use changes. Separately and combined, these natural processes can drastically affect the earth's climate (CDWR 2015). Climate models can help predict impacts to ecology and wildlife, which can be used to provide insight on how active management policies can be tailored to future needs.

Species-climate models, or climate envelope models, employ historical ecological and qualitative data on species interactions to assess past, present, and future conditions of endemic species and their vulnerability to climate change (University of Florida). These models can be used to hypothesize how species will be impacted by the effects of climate, but highly variable factors such as temperature and precipitation require an ensemble of climate change projections to create dependable models. Also, the effects of climate change can be difficult to predict at the local and regional level, so several climate models are often used to corroborate results. However, by utilizing these models, we can begin to understand how the landscape matrix and underlying ecological framework will change over time within our study area and respond by suggesting measures to implement that will conserve ecological function and maintain resilience of populations (Watling 2014).

MaxEnt is a type of climate model that can be used to calculate the probability of target species habitat under a variety of climate scenarios. By employing species distribution data and projected climate changes on downscaled climate maps, it is possible to predict habitat probability for different species for both the present and the future. MaxEnt models play an important role when assessing how certain species' habitat will change over time, and can provide insight on the suitability of a region under a variety of scenarios.

Climate Scenarios

Two families of scenarios are commonly used for future climate projections: the 2000 Special Report on Emission Scenarios (SRES) and the 2010 Representative Concentration Pathways (RCP). The SRES scenarios are named by family (A1, A2, B1, and B2), where each family is designed around a set of assumptions about emissions. In contrast, the RCP scenarios are simply numbered according to the change in radiative forcing, or difference between the amount of sunlight absorbed by the earth and the energy reflected back into space, ranging from +2.6 to +8.5 watts per square meter by 2100. This model replaced the SRES standards in the IPCC's Fifth Assessment Report (AR5) published in 2014 (Melillio et al. 2014). There are four pathways for RCPs: RCP8.5, RCP6, RCP4.5 and RCP2.6, also known as RCP3-PD. Each

Representative Concentration Pathway is described with a number which indicates the forcings for the RCP, while PD stands for Peak-Decline (Wayne 2013). These four projections are significant because each RCP predicts the outcome of a different climate scenario, and are important because each simulation can be used to predicts how their projection will have an impact on human systems, physical changes, and biological systems.

The SRES family of scenarios shows projected trends of global greenhouse gas (GHG) emissions using the GFDL 2.1 climate model. A1 experiences rapid economic growth and introduction of new technologies, which are more efficient, but emphasize the use of fossil fuels. If this scenario occurs, it will produce the greatest level of GHG emissions. This is followed by the A2 scenario, which denotes stunted and more fragmented technological change and economic growth. Population growth increases in this scenario, but it leads to slightly lower emissions for the twenty-first century overall, compared to the first. The third, B1, would be the ideal situation with reduced material intensity and a focus on social equity. This scenario also involves rapid change in economic structures toward service and information, with an emphasis on clean, sustainable technology, leading to the lowest estimate for emissions for the twenty-first century (Mote et. al 2011).

Temperature, Precipitation, and Hydrology

Rising temperatures are often the strongest driving force for impacts to climate. (Gonzalez 2011). Temperature projections by the Scripps Institution of Oceanography indicate that by 2060-69, mean temperatures will be 3.4 to 4.9°F higher across California than they were in the period 1985-94. The average mean annual temperature in the Sacramento–San Joaquin basin is projected to increase by 5 to 6°F during this century, though with substantial variability in the Central Valley (CalAdapt). In addition, the duration of extreme warm temperatures -- which are classified as ten degrees above the average high temperature for the region -- is expected to increase by as many as sixty days (*Id*). While uncertainty in temperature projections may make it difficult to accurately predict future impacts to biodiversity and the landscape, models can be effective in recognizing trends that pose possible threats to wildlife. Maximum temperatures are expected to increase by 5.8°F between now and 2040-2099. Even though temperatures are expected to increase consistently across landscapes, higher elevations tend to be 7-15°F cooler than foothills and valleys (*Id*).

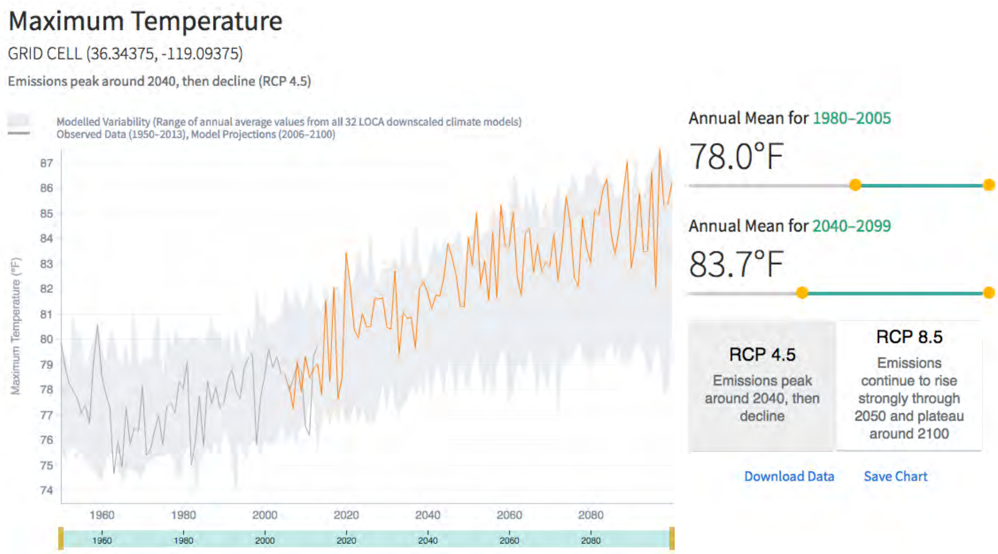

Figure 3: *Average maximum temperatures at foothill and valley region between 1950 and 2100 with averages shown between 1980-2005 and 2040-2099 (CalAdapt)*

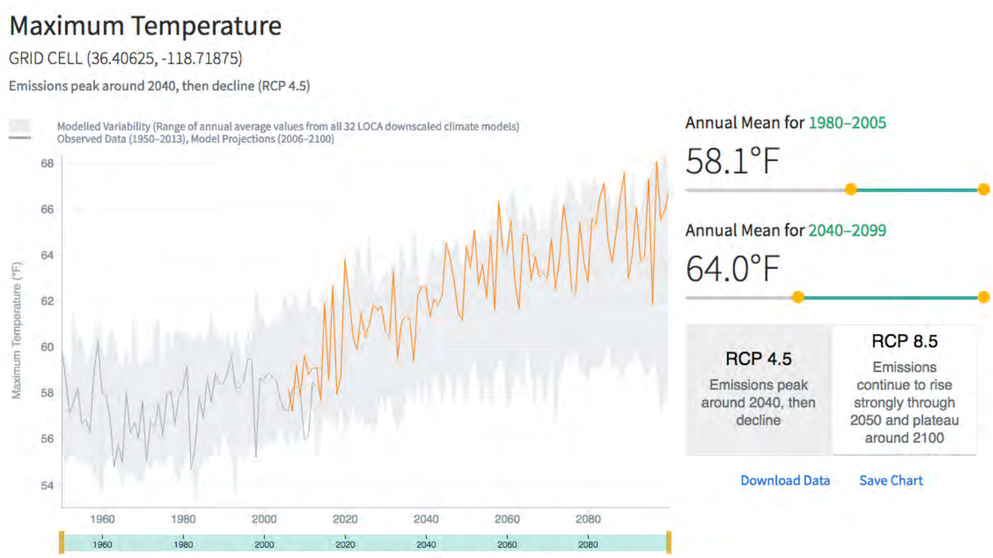

Figure 4: *Average maximum temperatures at potential corridor option 1 between 1950 and 2100 with averages between 1980-2005 and 2040 - 2099 (CalAdapt)*

Future climate projections based on temperature and precipitation for our project area can be found in the appendix section of this report and were gathered from climate tools on the CalAdapt website, using the GFDL CM-3 model and a RCP4.5 scenario.

Rising air temperatures are expected to generate noticeable disturbances in streamflow, water temperatures, overflow capacity of reservoirs, and water quality in SEKI and surrounding areas, which will all lead to further disruption of habitats. Air temperature is projected to increase by 1.8°F (1°C) by 2030, which will reduce the average annual volume of water produced from snowmelt by approximately 15% (Garrison, et al 2009). While it is difficult to accurately predict future patterns of precipitation, the IPCC generally suggests that there will be a 5-20% reduction of total precipitation worldwide. Although parts of Northern California may experience heavier storm events and higher annual rainfall, it is predicted that the total precipitation in the state will be 15-35% lower in the upcoming century overall (DiPietro 2016). Throughout our project area, annual average precipitation is expected to decline by about 0.5-1.5 inches over the course of the century, but it is expected to have more precipitation in general at higher elevations (see appendix).

As a result of higher temperatures and reduced precipitation, snowmelt from the Sierra Nevadas is expected to occur earlier in the year. This could produce greater amounts of runoff sooner in the year and therefore leave less water availability during the dry months of late spring and summer, when it is needed most. Global warming will also lead to a greater amount of precipitation occurring as rainfall rather than snow in lower to middle elevations of mountain catchments, reducing potential snowpack storage which California ecosystems and human population rely on heavily. In the Sierra Nevada, just north of the Central Valley, there is projected loss of 30-40% snow water by 2050 and a 65% decline in snowpack by the end of the century (NRCS). In the mountainous regions of SEKI, annual average snow water equivalence is expected to see a 4.1-inch decline (about 10% decline of current annual monthly averages) during February and up to 6-inch decline (up to a 23% decline) during April between now and 2040-2099 averages (see appendix). This reduction in snowpack going into the summer is expected to compound impacts of water deficit currently being felt by the Central Valley. Furthermore, according to the California Climate Change Center, late spring streamflow could drop by as much as 30% leaving less frozen snow late into the season (CalAdapt).

A report released by the Bureau of Reclamation concluded that estimated declines in precipitation and rising temperatures in the Central Valley, along with population growth, will directly impact water supplies, water quality, fish and wildlife ecosystems, and flood control in California's Central Valley (USDOI 2014). This includes the elimination or decline of certain keystone species, which could alter food webs and have detrimental effects to overall ecosystem health. For example, it is predicted that after 2065, waterbird habitats, which primarily consist of wetlands, are projected to decline by 15% due to severe warmer, drier climates (Matchett & Fleskes 2017). The effects of drought and rising temperatures will devastate habitat in the region. These climate models lead us to believe that our study areas must take water supply and storage during dry years into consideration when assessing viable corridors.

Other Residual Impacts

As a product of lower precipitation and hotter temperatures, soil moisture in the Central Valley is predicted to decrease by about 15-20%, causing the yearly average climatic water deficit to increase. This deficit is measured by the plant water demand unmet by soil moisture and is expected to exceed historical values by 2030 (CalCommons). Dry soil may also pose a problem for sequoia seedlings within 25 years and for the sequoia trees in every stage of their life cycle in the next 50 years, resulting in a decline in mature sequoias within 100 years. This phenomenon has been linked in part to increasing temperatures and drier climate, which impacts many tree species, including the valley oak. In addition, other threats such as disease, introduction of nonnative species, and presence of insects are predicted to also contribute to these rising mortality rates (Lindenmayer et al. 2012).

Ecosystem Resilience and Connectivity

Climate change adaptation is defined as minimizing the negative impacts of global warming on vulnerable aspects of the natural environment (Mawdsley 2009). Management of existing, suitable habitats must be improved to conserve their functions and prevent further degradation (Steel 2011). Building a corridor to allow for species to migrate to more suitable habitats is a viable way to ensure resilience and recovery of populations, but some species or populations may require alternative options if they do not or are unable to migrate to better quality habitat.

Since the effects of climate change on interspecies behavior are not well known, it may be more important to focus on habitat quality and connectivity depending on circumstances. Quality, dispersal, and aggregation of habitat all play key roles in determining habitat connectivity (Hodgson et al. 2009). Each of these factors must be taken into consideration when planning viable corridors.

There are a large array of management techniques that could be employed to enhance migratory permeability, or the accessibility and ability for species to move within a landscape. Options include establishing easements on privately owned land, providing vegetation for feeding and protection of focal species, or removing physical barriers such as fallen trees or debris from otherwise navigable corridors. The availability of suitable habitat plays a critical role in the survival of a species during relocation. If an area is heavily fragmented, the range of expansion and speciation is heavily limited, both spatially and in terms of resources (Donald & Evans 2006).

The National Park Service can use a variety of modeling methods to analyze the estimated extent and severity of climate change impacts on ecosystems, and take steps to manage the landscape to fit the needs of different species. By pinpointing biological hotspots and habitats threatened most by climate change, certain areas can be prioritized to best conserve their ecological functions (Millar & Woolfenden 1999). In low-lying foothill habitats, the proper connections must be made so species can migrate to higher elevations in response to rising temperatures, while assessing how higher elevation habitats and their suitability will change in response to these stressors.

CORRIDOR FUNCTIONS, FEATURES, AND MODELS

Wildlife Corridors

By connecting the Valley fragments to the continuous gradient of habitats in SEKI, wildlife corridors can provide species the opportunity to migrate to higher elevation in response to climate change. A wildlife corridor is an area that links two or more habitats together to maintain historically contiguous habitats in order to combat fragmentation and thus preserve biodiversity (Beier & Loe 1992).

Corridors fulfill five basic criteria: they allow animals to travel, plants to propagate, genetic exchange across different populations, migration by populations in response to environmental impacts or natural disasters, and recolonization of locally extinct areas (Beier &

Loe 1992). Wildlife corridors can also facilitate simply increasing the total area of available habitat (Tewksbury et al. 2002). Corridor planners must include elements that are species specific, account for urban development, restore habitat near areas that cross boundaries like major roads, and pay attention to edge effect (Beier & Loe 1992; Clevenger & Waltho 2005; Ng et al. 2004). While the spectrum of corridors is large, almost all focus on a few target species, instead of an entire ecosystem. Specific types of corridors are discussed below, but in general, species-specific corridors are more effective than general purpose ones because different species have different habitat requirements (Fleury & Brown 1997).

Corridor Classifications

Corridors have been classified in many ways. Some studies classify corridors as either single stripes of unbroken land or as stepping stones – small areas of habitat without a direct link, such as a few lone trees in a plain (Pérez-Hernández, Vergara, Saura, & Hernández 2014). Others draw a line between man-made and natural corridors (Beier & Loe 1992). Others base their classifications on geography, such as stream corridors and forest corridors (Perault & Lomolino 2000). And still others classify corridors based on what specific organism the corridor is intended for (Fleury & Brown 1997). This organism-based classification system is the most popular because its specificity partially accounts for factors including geography and habitat continuity.

Wildlife corridors for large mammals such as bears, cougars, and elk tend to be large and wide unbroken strips, and can succeed as both long and short corridors. In urban areas, many large mammals use freeway overpasses as corridors. Large mammals may cross the corridor or, if the corridor is large enough, may live in one (Haas & Crooks 2001; Clevenger & Waltho 2005). Medium sized and small mammals such as coyotes, roe deer, and rodents generally prefer shorter, narrower, and more secluded corridors. In urban areas, they travel best in freeway underpasses (Ng et al. 2004; Ramiadantsoa et al. 2015). Most birds prefer stepping stone corridors, corridors made up of small loosely connected micro-habitats like trees, rather than a single continuous corridor (Sekercioglu 2009; Pérez-Hernández et al. 2014). Insects are generally able to survive in fragmented habitats without corridors connecting them, when other organisms would die out. Still, insect populations and gene flow are benefited by constructing small-scale corridors, such as planting butterfly friendly flowers in a garden (Nicholls, Parrella, & Altieri 2001; Öckinger & Smith 2008; Vergnes, Viol, & Clergeau 2012). Plant species are able to survive in most man-made corridors, but do best when their natural corridors are preserved. Plants take much longer to cross a corridor than animals do and so preserving the range of their natural habitat is the best way to protect them (Perault & Lomolino 2000).

Inter-species interactions are vital components of regular habitat, and should be accounted for when designing a corridor. For example, animal corridors that also provide space for plants to migrate will foster exchange of animals between two habitats, and will also facilitate pollination and seed dispersal. This inter-species consideration has positive impacts on both organisms (Tewksbury et al. 2002).

Modeling

Modeling can be used to remotely locate and optimize corridors.With the geographic locations of optimal corridors known, organizations such as SEKI can take steps to negotiate easements, build better connectivity, or implement other methods to protect and improve the land in those locations. Corridors can be modeled in a variety of ways. Circuit models translate electric circuit theory to species movement (McRae et al. 2008). Least cost models take inputs of resistance values to output paths with highest permeability (Adriaensen et al. 2003). The graph-theoretic approach modifies this to output more options, represented by nodes and edges of a graph (Pinto & Keitt 2009). Central to all of these approaches is deciding what to input. Models can be based on an array of factors including naturalness, animal behavior, and habitat suitability and can include a range of subjects from a single umbrella species to no specific species at all.

Least Cost Paths

The most common approach to modeling corridors is known as the least cost path model. In least cost models, every landscape unit or grid cell is assigned a resistance value based on how much the features of that cell, such as topography, vegetation, or development, will hinder the movements of the species in question (Adriaensen et al. 2003). The algorithm then outputs a least cost path based on "effective distance," which is similar to Euclidian distance but incorporates the sum of the resistance values that the corridor passes through. Most GIS systems contain a least cost path toolbox, making the method widely available, and the results generally unambiguous. Concerns lie in uncertainty introduced by assumptions made regarding resistance values and species behavior.

In the absence of empirical data, scientists often rely on expert opinions to create parameters of resistance and animal behavior. For example, a 2008 study modeling dispersal corridors for cougars used a survey of experts to parameterize habitat suitability (LaRue & Nielsen 2008). They then ran a least cost path simulation and added a one kilometer buffer to create a least cost corridor. In their model, resistance was thought of as the inverse of habitat suitability. This approach to resistance raises some concerns. First, parameters based on opinions have greater error than parameters based on empirical data, but for large areas or for studies with limited resources, this may be the best or only option. Second, using habitat suitability as a proxy for how animals will move introduces additional error. Behavioral data is superior to habitat suitability in this regard. Parameters based on traveling animal resource selection are noticeably more accurate for corridor modeling than parameters that do not take behavioral state into consideration (Abrahms et al. 2016). While many studies use a large carnivore as an umbrella species for corridor modeling, a superior approach is to use multiple focal species that include but are not limited to one trophic level such as carnivores (Beier et al. 2009). An important note on least cost path models is that they assume animals will always take the optimal path of least resistance to their desired destination which is not always the case in reality (Cushman et al. 2013).

Project Significance

Anthropogenic climate change poses a grave threat to species and ecosystems and has only been a major part of corridor modeling research for the past decade. Connectivity and protected area management are the methods of climate change conservation that offer the greatest potential to save species (Hannah 2011). Connectivity only works if there are healthy habitats that can be connected, creating a race between climate change response and habitat loss. There is a threshold of habitat loss that, once passed, will dramatically narrow species' ability to survive a changing climate (*Id*). Little consensus exists on how to best model corridors. Each approach brings with it a new set of assumptions and uncertainty. The correct approach for a given project greatly depends on the scope, budget, and goal of the project. What is certain is that modeling and mapping dispersal corridors has huge potential in global conservation efforts, and would make a large impact in the San Joaquin Valley.

Research Questions

The three research questions this study addresses are:

1. What habitats currently exist in the foothill and valley region of the Kaweah Watershed, how are species distributed within them, and how fragmented are they?
2. What is the current state of protected habitat area in the region, and what potential corridor options does current land use allow for?
3. How will climate change impact habitats, species distributions, and potential corridor locations in the future?

We chose these three research questions because they focus on protecting species located in fragmented habitat, are in line with our client's interests, and are feasible to answer within the project timeline.

The first two questions focus on researching the current state of the foothill and valley region outside Sequoia National Park. In order to mitigate biodiversity loss, we needed to know what habitats and populations exist and how fragmented they are. Because corridors are species specific, this information helps us better understand the appropriate types of corridors for this region. We also needed to understand the current state of wildlife corridors - where they are, what species they are used by, and what state they are in. Finally, in order to plan new corridors and protect existing ones, we have to understand the land use distribution in this region.

With the third question, we hoped to gather enough data to understand the downscaled effects of climate change in this region and future-proof our corridors as best we could.

Methodology

STUDY AREA

The entire San Joaquin Valley is under immense stress from the land use changes, drought, climate change, and urban development that will cause continued stress in our focal area, the Kaweah Watershed. The Kaweah Watershed lies adjacent to the eastern edge of SEKI and extends from the park into agriculture dominated land on the Valley floor. From the east to west, our study area extends from the Sierra Nevada Mountains to the 99 Freeway. From the north to the south, we chose study area boundaries that would include the entire Kaweah Watershed (Figure 5). We chose these specific boundaries because the 99 Freeway would serve as a large boundary for animals to pass to reach the park and to the eastern edge of Sequoia to look at any corridor options surrounding the park. The study area includes large areas of protected lands within the park and small pockets of protected land that range from city parks to preserves that was gathered from the California Protected Lands Database.

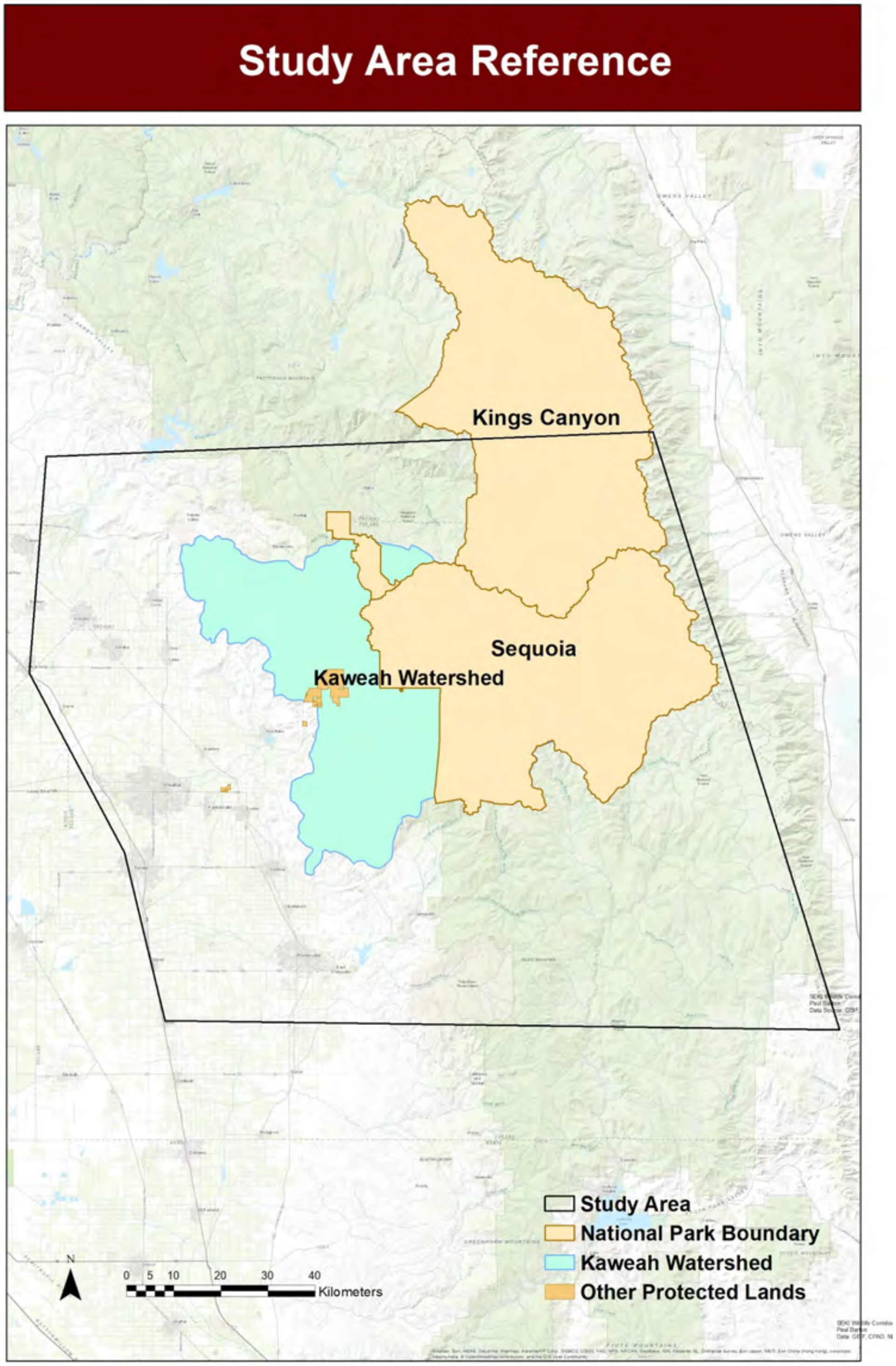

Figure 5: *Map showing the study area and location of the Kaweah Watershed in relation to the park as well as protected areas within the study area.*

UMBRELLA SPECIES: WESTERN POND TURTLE, WESTERN FENCE LIZARD, GOPHER SNAKE, VALLEY OAK, BLACK BACKED WOODPECKER, AND MULE DEER

Wildlife corridors are most effective when they are species-specific (Fleury & Brown 1997). Though there are many possible approaches to choosing focal species, we followed advice from our client to choose several species that would benefit from a corridor, would be likely to use a corridor, were representative of other species in the region, and had a diverse set of corridor requirements. After consulting with biologists from the National Park Service and conservationists with the Sequoia Riverlands Trust, a nonprofit organization that manages several reserves in the region, our team decided to focus our assessment and design of corridors on the following species: western fence lizard, western pond turtle, gopher snake, mule deer, valley oak, and black backed woodpecker.

Western Pond Turtle

The western pond turtle is a generalist reptile species with a more specific set of corridor needs than the other reptilian focal species. This species requires a corridor that can be lived in not just traveled through, since the average male western pond turtle only moves about 354 meters in total during the summer months (Lovich 1998). Turtles prefer habitat that has minimal slope and is situated near a body of water. Western pond turtles would require an available body of water streams, rivers, or ponds to use to be able to live within a corridor. The western pond turtle is expected to lose habitat in our study area and across the Valley as climate change creates drier conditions. Because of this expected habitat loss, the National Park Service and the Sequoia Riverlands Trust recommended we include the western pond turtle.

Western Fence Lizard and Gopher Snake

Compared to the western pond turtle, the western fence lizard and gopher snake have much broader habitat requirements, but also require a corridor that they can live in. Both species are capable of living and migrating in a variety of habitats including grassland, chaparral, riparian, woodland, open forest, and farmland. These two species were similarly recommended by members of the National Parks Service and the Sequoia Riverlands Trust.

Valley Oak and Black Backed Woodpecker

The valley oak and black-backed woodpecker have a distinctly different set of corridor requirements from the other focal species. Valley oak is a keystone species of riparian habitat, one in which many other species in the study area reside. To successfully migrate through a corridor, valley oak requires many generations for acorns to be dispersed long distances by birds such as the California scrub jay and various species of woodpecker, such as the black backed woodpecker. Valley oak, which are under stress from the drying climate, can be found in the Kaweah Oaks preserve. The black backed woodpecker requires corridors with alternating zones of high canopy density and low canopy density as these species generally forage in heavily canopied habitat and nest in semi-open habitat. In addition to valley oak, the woodpecker was recommended by members of the National Park Service and Sequoia Riverlands Trust. After examining our available data, our team chose to study the black-backed woodpecker as we had the most complete data set for it.

Mule Deer

The mule deer, a generalist mammal, was also included as a focal species to consider the separate set of habitat requirements for large mammals. Unlike the previously mentioned species, mule deer can migrate over large distances with a wide range of slope and habitat conditions. Corridors designed for mule deer generally consist of continuous strips of land. As a large prey mammal, mule deer location serves as a good indicator for determining predator location. Both the National Parks Service and Sequoia Riverlands Trust recommended including the mule deer in our umbrella species.

Exclusions

We excluded amphibians from our umbrella species list because their needs are mostly met by the inclusion of the western pond turtle, for which more data on species presence and behavior is available. We excluded small mammals from our species list because, after consulting both park biologists and local conservationists, we could not determine a species that would both utilize a corridor and necessitate one. Finally, we excluded predators from our list because park biologists informed us that most predators in the region follow prey species movement and are able to travel without the use of corridors.

CRITERIA FOR LEAST COST ANALYSIS

We analyzed several research papers regarding least cost corridors and determined four criteria to evaluate: land use / vegetation type, slope, human population density, and road density. These four criteria were commonly used in similar case studies and had a strong effect on species location, migration, and habitat suitability (Zeller et al. 2012). Though initially considered, the Human Influence Index (HII) - a measure of human impact in an area based on population, infrastructure, and other factors - was not used as a criteria to determine corridors. The HII is based on a scale of 1 kilometer, but our population and road density maps also show areas with the highest human influence at a higher resolution.

We assigned each criteria numerical values between 1 and 10 to compute our least cost paths in which the lowest value correlate to areas of least resistance. We created resistance values based on values used in similar case studies, such as “Use of Resistance Surfaces for Landscape Genetic Studies: Considerations for Parameterization and Analysis” by Stephen F. Spear and “Using Weight Distance and Least-Cost Corridor Analysis to Evaluate Regional-Scale Large Carnivore Habitat Connectivity in Washington” by Peter Singleton, and research on focal species behavior. General values for vegetation, slope, population, and road density were created for each classification based on the overall preference of species in the study area; most of whom prefer riparian habitat, low development, low slope, low population, and low road density. Each criteria was then weighted based on that criterion's relative importance to each focal species, i.e. the mule deer was not affected by slope and was given a weighting score of 0 to reflect that (Table 1).

DATA COLLECTION

Our data collection began by asking different groups, from regional nonprofits to large government agencies, for data or GIS layers regarding species location and land use in the area.

We compiled this data for future research in the project area, please see Appendix D: Contacts for contact information.

Species Data

In order to collect species specific location data, we looked at both the Global Biodiversity Information Facility (GBIF) and the California Natural Diversity Database (CNDDB). GBIF is an international, open data source that is funded by governments. CNDDB collects information on rare or endangered species and is managed by the California Department of Fish and Wildlife. Because of this distinction some of our species, like the mule deer, are not found on CNDDB. Also, some CNDDB data points for the species dating from the early 1900's we decided would not be as accurate as more current data due to changes in land cover and climate over time. Because of these two challenges with CNDDB, we decided to use GBIF for the presence data for our six focal species. However, this still only gave us presence data for each species; using species data and climate data we were able to use Maximum Entropy (MaxEnt) software to project absence data.

Valuation Data

The least cost path criteria - land use / vegetation type, slope, population density, and road density - were determined based on the most popular and applicable criteria used in previous corridor research projects. The land use / vegetation data used is from USDA Forest Service National Forest Types Dataset. We chose this data for vegetation because of its detail and inclusion of developed areas. The slope data is USGS topography. Population density data is from Tulare County and is based on the 2010 Census information. Road density was calculated using data from CalTrans, including major highways as well as county and city roads. Although the road density map does not include dirt roads, we believe it is still a good criteria for least cost analysis as paved surfaces serve as a larger barrier than unpaved ones.

CORRIDOR CONSTRUCTION

Corridors were constructed using the Cost Path tool in ArcGIS and later refined using MaxEnt as described in the MaxEnt section below. Cost rasters for each criteria were created then used to make cost distance and cost back link layers in ArcGIS. The Cost Path tool in ArcGIS used these layers to create the path of least resistance based on our values, from a starting point to an end point at the parks' border for each of our focal species.

Cost Raster Creation and Weightings

We created one general cost raster that was used for all species, with each criteria weighted differently per species (Appendix B, Tables 2-5). We assigned values from 1-10 for each cost path criteria in which categories with low values are less resistant and categories with high values are more resistant, for example we assigned a 1 for California Montane Jeffrey Pine Woodland and a 10 for Developed, High Intensity. Values for vegetation type / land use were based on research in riparian species behavior - vegetation types were given low values if they are naturally seen in riparian habitat and high values if they are not, all developed areas were given high resistance values. Values for slope, population density, and road density were based off previous corridor case studies and frequently used cutoff values, all get more resistant as their value increases.

Table 1 displays our criteria weightings per species. Each criteria was given a weighting based on its relative importance to the biological and behavioural requirements of each specific species as determined by behavioural reports on each species and corridor case studies that use similar species. Several criteria were determined not to impact species movement, such as slope for the black-backed woodpecker, and were given a "0" weighting to remove it from the least cost calculations.

Starting and Ending Points

The starting points for each corridor included two of the few remaining riparian habitat areas in the study area: Dry Creek Preserve and Kaweah Oaks Preserve. Both preserves are operated by the Sequoia Riverlands Trust. Dry Creek Preserve is a 152 acre, restored foothill and alluvian sycamore habitat acquired by the Trust for restoration in 2004 (Dry Creek Preserve 2017). Homer Ranch and Mitigation Preserve are additional preserves in the area that lie close to Dry Creek. Homer Ranch is also operated by Sequoia Riverlands Trust and Mitigation Preserve is operated by the Kaweah Delta Water Conservation District. Due to their proximity we chose to only use Dry Creek as a starting point for potential corridors.

Kaweah Oaks Preserve, has contained a protected valley ecosystem and valley oak habitat of over 324 acres since the mid-1900's. This area is one of the few areas that protects valley oak, which is important as their populations are dwindling potentially due to drought. (Kaweah Oaks Preserve 2017).

One additional starting point was selected for the western fence lizard. We created species hot spot maps to determine if there were any large populations outside of protected areas inside the national park boundaries. While many species showed hot spots, the western fence lizard was the only of our umbrella species to have one outside the parks.

The ending point for all corridors was selected as the western border of Sequoia and Kings Canyon National Parks. After speaking with Christy Brigham and Paul Hardwick, we decided to use the entire park as a potential end point as it would allow for the most potential corridor paths to the park, and because there are no major geologic features on the western border that are likely to prevent species movement. All starting and ending points are shown in Figure 6.

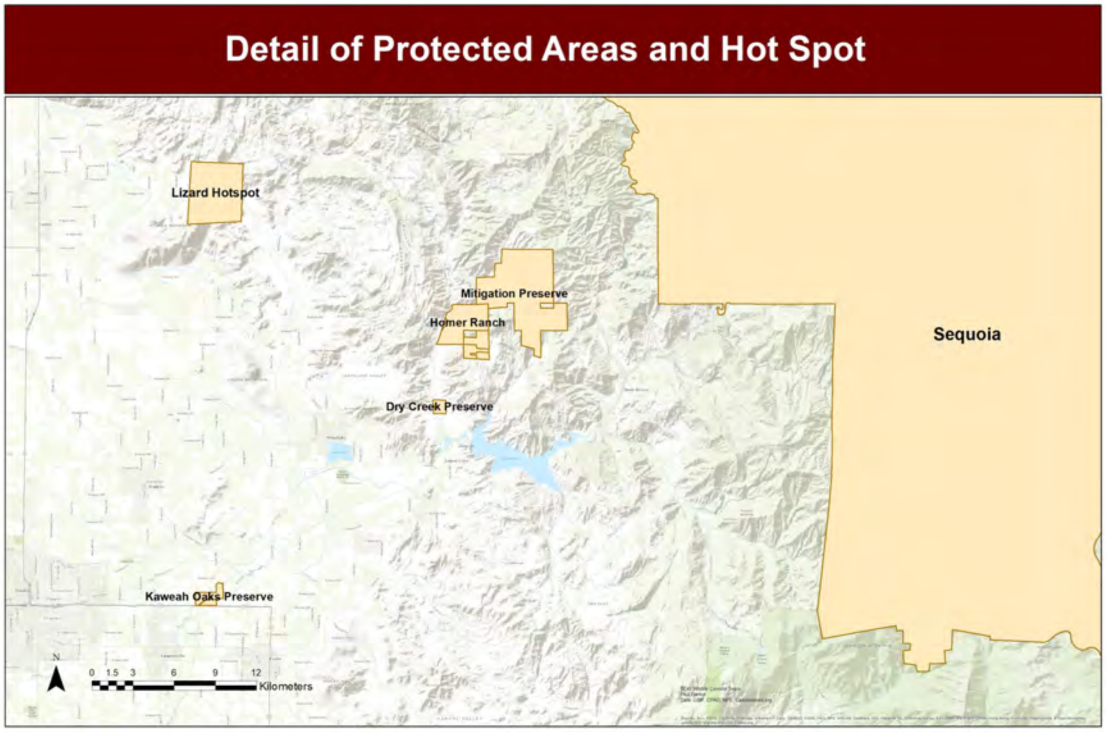

Figure 6: *Protected areas, inside and outside SEKI, with lizard hotspot.*

Cost Path Tool

We used the Cost Distance and Cost Backlink tools in ArcGIS with our cost raster, weightings, and starting and ending points. The Cost Distance and Cost Backlink outputs were then combined using the Cost Path tool to create our least cost paths for each species from each starting point, then merged to show every least cost path to the park per species.

Criterion	Western Pond Turtle	Gopher Snake	Western Fence Lizard	Valley Oak	Woodpecker	Mule Deer
Land Use	0.7	0.6	0.6	0.7	0.8	0.6
Slope	0.1	0.1	0.1	0.1	0.1	0
Population Density	0.05	0.1	0.1	0.1	0.1	0.2
Road Density	0.15	0.2	0.2	0.1	0	0.2

Table 1: *Criterion weightings for each focal species.*

<u>MAXENT</u>

MaxEnt software uses climate and species presence data to create a habitat probability model for a given region. We used it to narrow down the least cost paths for our species by choosing the paths that went through the best habitat, using both current and future climate data and projections for the region. We ran MaxEnt for historical (1981-2010) and future climate scenarios (2040-2069 and 2070-2099) under the climate model GFDL 2.1 A2 from CalCommons.org. We chose GFDL 2.1 A2 to be consistent with previous research conducted by SEKI staff. In MaxEnt, we ran each focal species under the three climate scenarios for ten runs with zero random test percentage and with random seed, and collected an average to account for variation in the model and give us the most accurate species habitat probability.

CORRIDOR ANALYSIS

We employed several methods to narrow down our corridors for each species specific corridors, considering the habitat suitability for each and the amount of intersection between different species corridors, then found the areas they overlapped to create our general corridor recommendations.

Species Specific Corridors

After creating our habitat probability projections using MaxEnt, we overlaid the least cost paths created in ArcGIS, for each umbrella species individually. We made judgment calls on which corridors would be best based on the current and future MaxEnt models by seeing which corridor followed the areas with the highest probability of habitat suitability for both the historical model and each future model. We were then able to select our chosen corridors and create new layers for each species that only included these optimal corridors.

General Corridors

We buffered each of our species-specific corridors by 250 meters on each side. Buffering allowed species corridors that were within 500 meters to overlap, we noticed that many potential corridors were close but not overlapping before adding a buffer perhaps due to the slightly different weightings of the values for each species. To determine the intersection of each corridor, we converted the corridors to rasters, assigned them a value of 1, and added the raster layers together. This method outputted a raster layer in which a value of 6 contained a corridor for all species, 5 for 5 of the species, and so on down to 0. We then chose four general corridors that were identified as optimal for the greatest number of species.

Results and Discussion

SPECIES SPECIFIC CORRIDOR RESULTS

Least cost paths were layered over habitat probability for three climate scenarios for each umbrella species.

Western Pond Turtle

The corridors for the western pond turtle, shown in Figure 7, primarily head northeast out of Kaweah Oaks Preserve to Dry Creek and the other preserves, before splitting in two: a branch that continues through protected lands northeast into the park, and a branch that takes a longer route southeast into the park. There is a high concentration of routes along both of these primary branches suggesting many suitable pathways in these areas, a conclusion supported by the highly-suitable habitat projected by MaxEnt along these paths. Other than the path between Kaweah Oaks and Dry Creek, which is unsuitable turtle habitat, the other main branches follow bodies of water to the park - which is essential for turtle corridors. The MaxEnt model shown in

Figure 7 shows higher probability in the central region of our study area that corresponds to lower development, with especially high habitat probability near major water features such as Lake Kaweah and the Kaweah River and its tributaries. The northeast branch to the park leaves Dry Creek and passes through protected lands in both Homer Ranch and Mitigation Preserve, then follows the North Fork Kaweah River to the Western border of the park. This is the best corridor for the western pond turtle because it is both the shortest distance from protected lands to the park and follows highly-suitable habitat. The second best option to the park is the bundle of corridors that head southeast from the split just south of Dry Creek. This corridor follows the South Fork Kaweah River all the way to the park - another highly suitable habitat region for turtles. This corridor is rated as the second choice corridor because it is longer than the first choice, despite also having strong potential. Both selected corridors are presented in Figure 8. In addition, both of these recommended corridors remain viable through 2099 according to our MaxEnt probability models, shown in Appendix C.

There are other branches of note such as the northern branch that breaks off just south of Homer Ranch, heading through moderately-to-highly probable habitat, and a branch that starts from Kaweah Oaks heading due east to the park. However these branches and the others similar to them are less suitable than the two defined above because they take a longer route from protected lands to the park and are thus harder to both create and travel through.

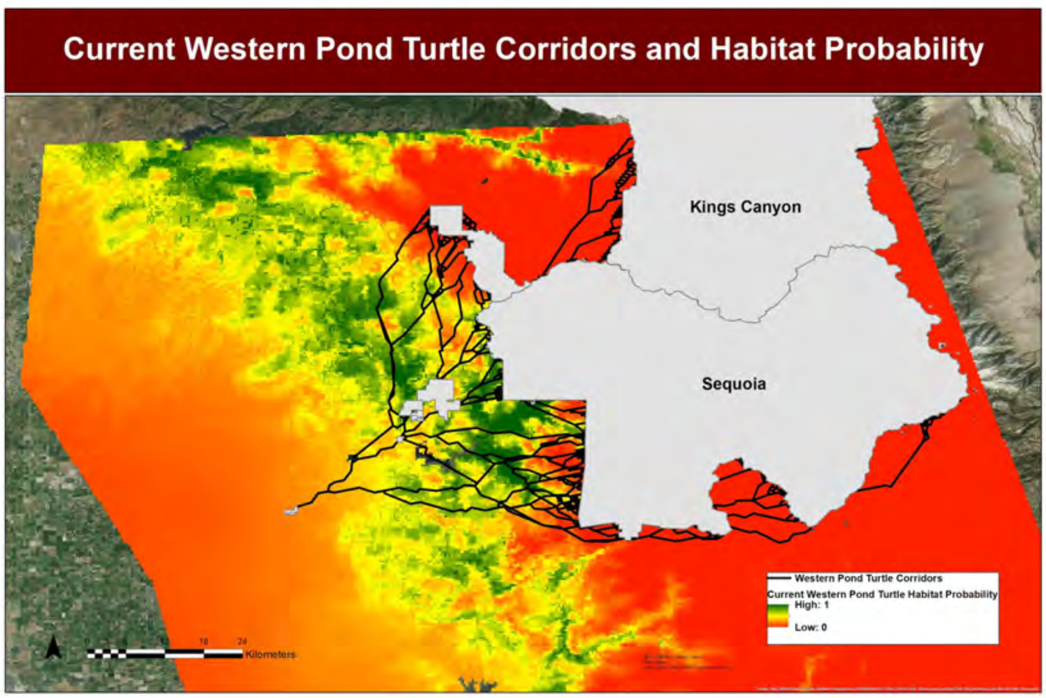

Figure 7: *Western pond turtle least cost corridors displayed over MaxEnt habitat probability for current climate conditions.*

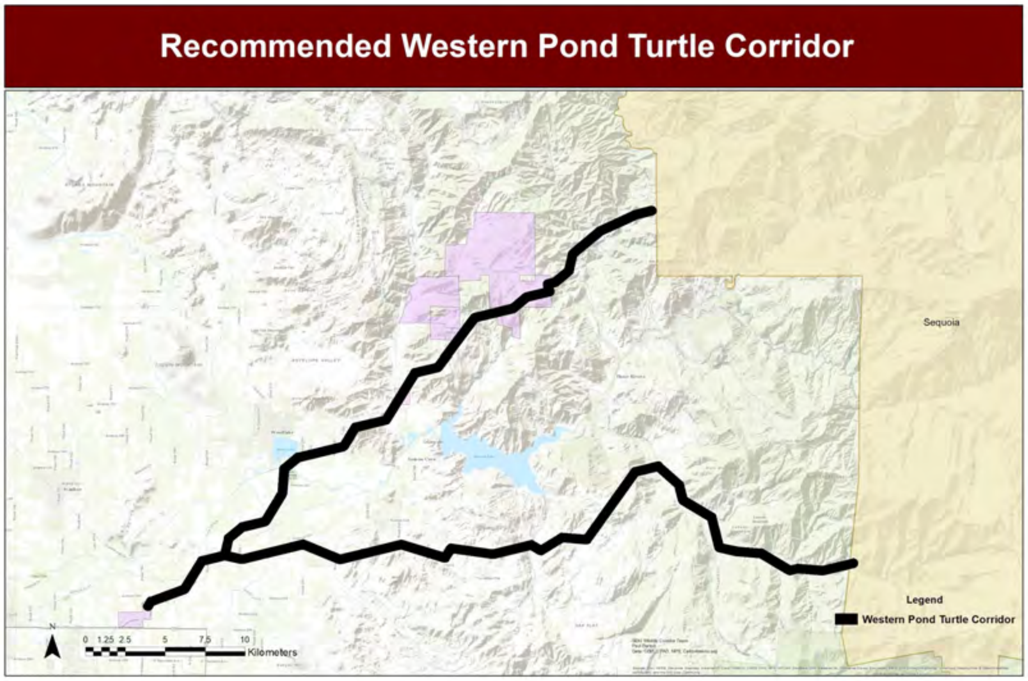

Figure 8: *Selected western pond turtle corridors.*

Western Fence Lizard and Gopher Snake

A single least cost analysis was conducted for both western fence lizard and gopher snake assuming identical resistance values and weightings for both species. Least cost paths for these species follow a similar pattern to those of other focal species, extending from Kaweah Oaks as a single path for approximately two miles before bifurcating into a northern and southern network of paths. While the corridors modelled for the focal reptiles follow the same general pattern of those for mule deer, the extensions are far less concentrated in the area immediately adjacent to the parks' borders suggesting that there is still a strong distinction between areas of high resistance and low resistance for reptiles. Another noticeable distinction in the focal reptile least cost path network is a large set of corridors that diverge from the northern branch before reaching Dry Creek that then lead directly north to Grant Grove. These corridors, however, are not ideal as they require a longer distance to migrate for focal reptiles located in the southern region of the study area.

MaxEnt models were created for each species individually and vary only slightly. MaxEnt localizes predicted current probable habitat for both species along the foothills adjacent to the western border of the parks. Models for climate scenarios show a slight decrease in probable habitat in the northern region of the study site and at the base of the foothills. Habitat probability, shown in Figures 9 and 10, is higher in the central region of the study area along the foothills bordering the parks. Predicted habitat probability for gopher snake is much more continuous than that of western fence lizard. However, habitat probability becomes significantly reduced between current conditions and those projected for 2070-2099 for both species (Appendix C).

Final selected corridors are similar for these two species, with a couple of notable differences. Both species follow a northeastern path from Kaweah Oaks to Dry Creek, and a northern branch that passes through Homer Ranch and Mitigation Preserve before connecting to the parks, and a southern branch that follows the South Fork Kaweah River before connecting to the parks. The western fence lizard path, however, passes best through the southern region of Homer Ranch and Mitigation Preserve, while the Gopher Snake path passes best through the northern. Also, the western fence lizard has an additional highly suitable path from its hotspot to the Western edge of Kings Canyon National Park.

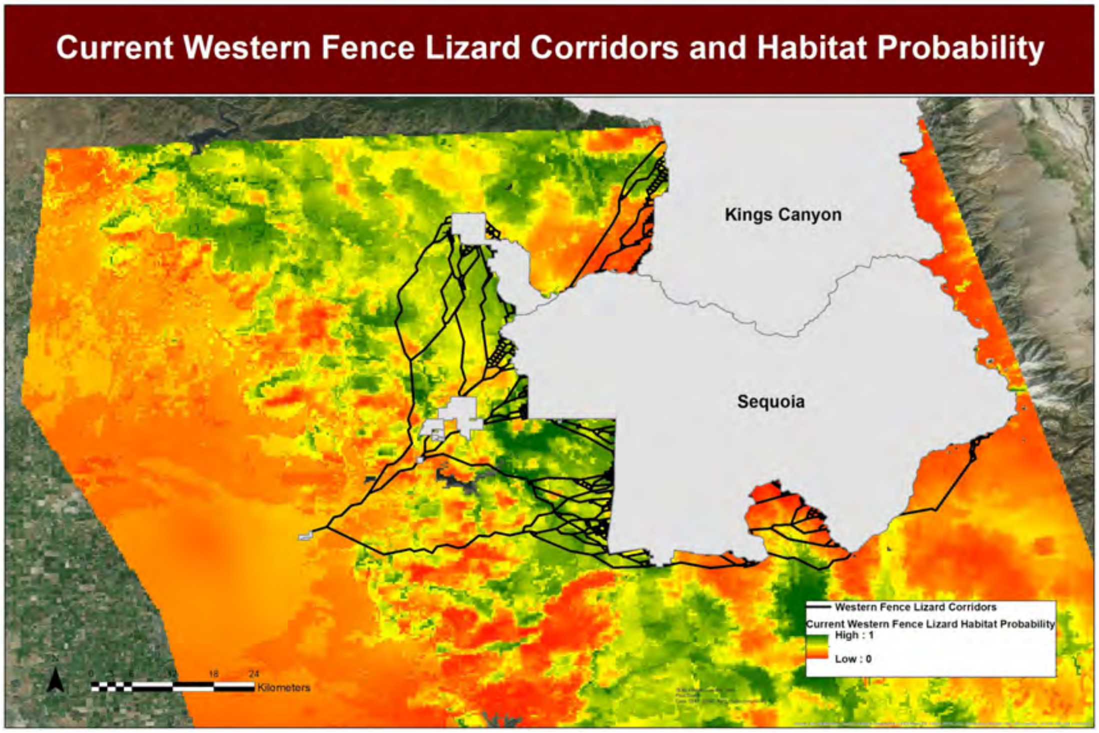

Figure 9: *Least cost paths overlaid on habitat probability for western fence lizard*

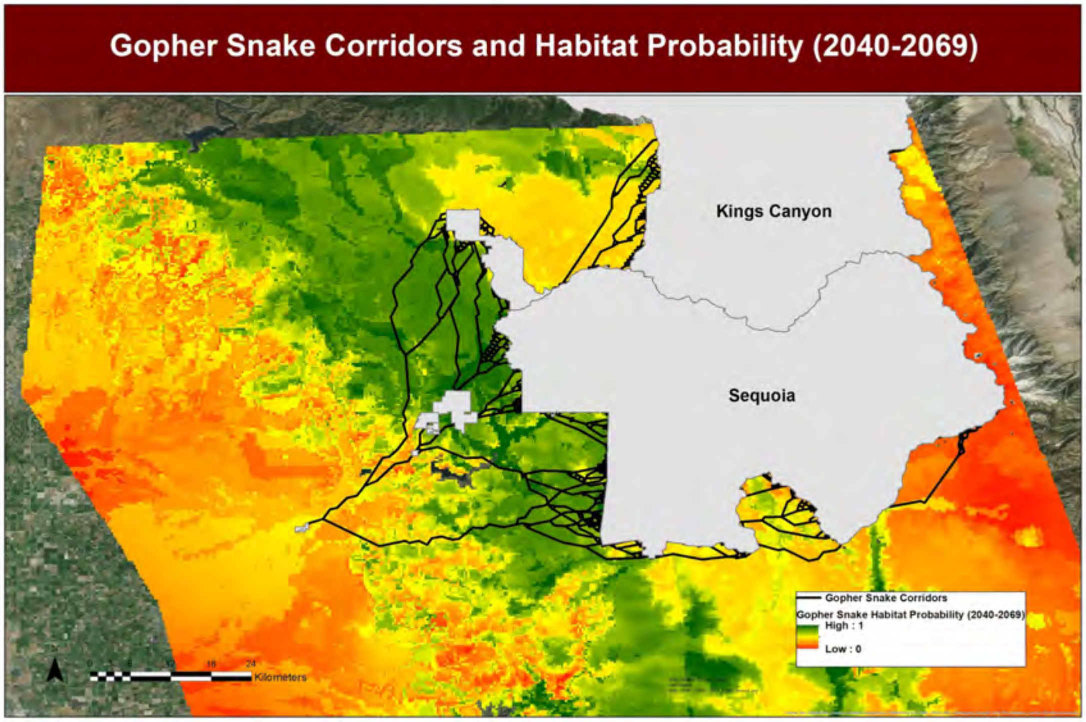

Figure 10: Least cost paths overlaid on current habitat probability for gopher snake.

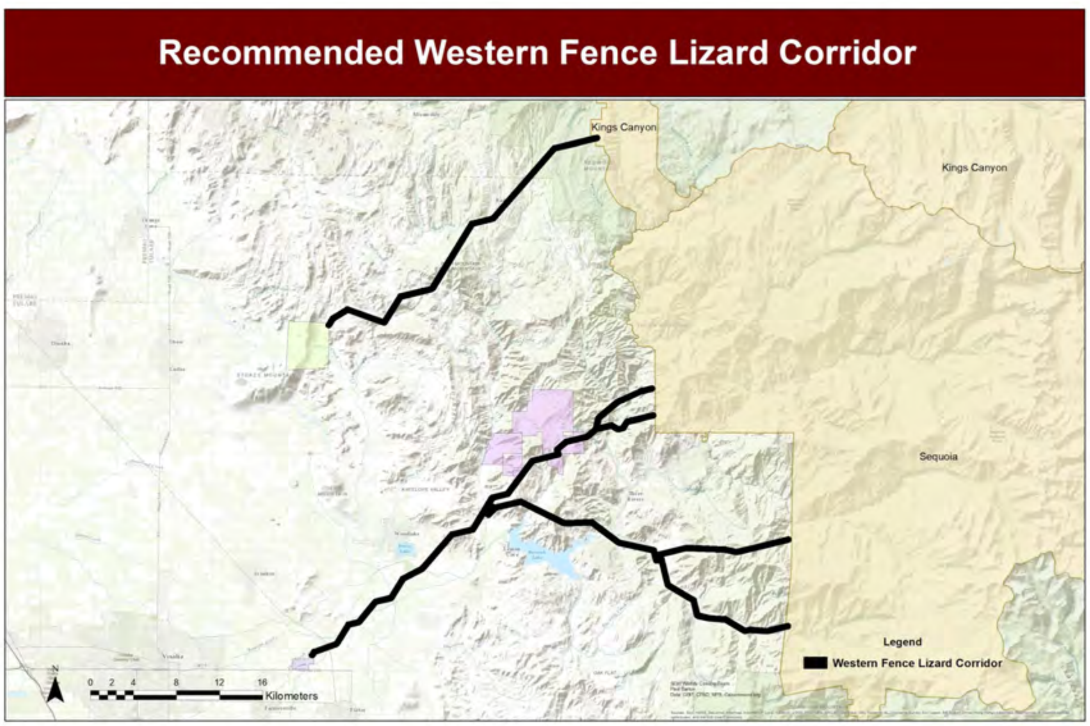

Figure 11: Selected western fence lizard corridors.

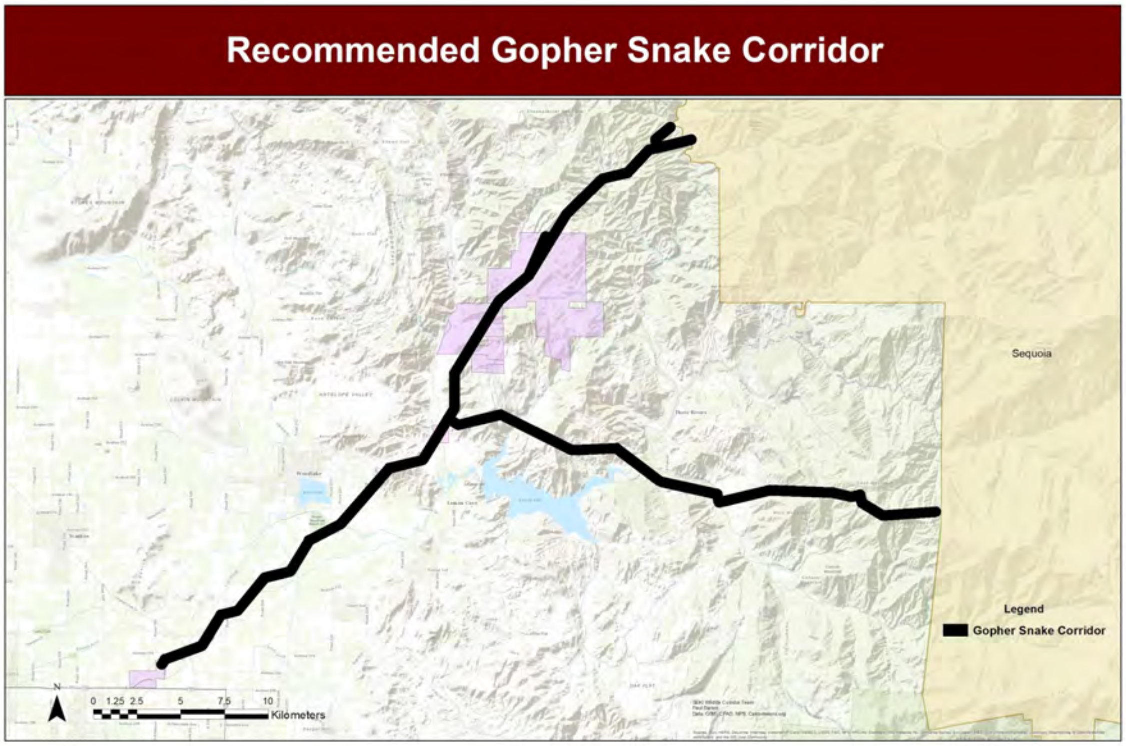

Figure 12: *Selected gopher snake corridors.*

Valley Oak

The final corridor selection for the Valley Oak was largely the same as for many other species. The two best general corridor locations, after connecting linearly from Kaweah Oaks to Dry Creek, are heading Northeast through Homer Ranch and Mitigation Preserve then following the North Fork Kaweah River to the park, and heading southeast from Dry Creek along the South Fork Kaweah River to the park. In addition, there are other potentially viable options heading due east from Kaweah Oaks and heading due north from Dry Creek to Grant's Grove.

Similar to the Black-Backed Woodpecker, however, is the very low habitat probability projected by our MaxEnt model for almost every region in our study area except for fragments in the center in and around the protected lands (Figure 13). The limited valley oak habitat only worsens in future climate scenarios shown in Appendix C. Despite the lack of probable habitat projected by MaxEnt, the selected corridors still offer the best pathways to the parks, passing through the most probable habitat possible and following water sources (Figure 14).

It is important to note that valley oak is the only umbrella species that does not have probable habitat within the park, as projected by MaxEnt. This is a major limitation for the species, as the valley oak may not migrate into the park at all, though this makes sense because the valley oak is a riparian species and there is very little riparian habitat outside the foothills. In future climate scenarios, the probable habitat will shift east towards the park, but still does not enter it by 2099 (Appendix C).

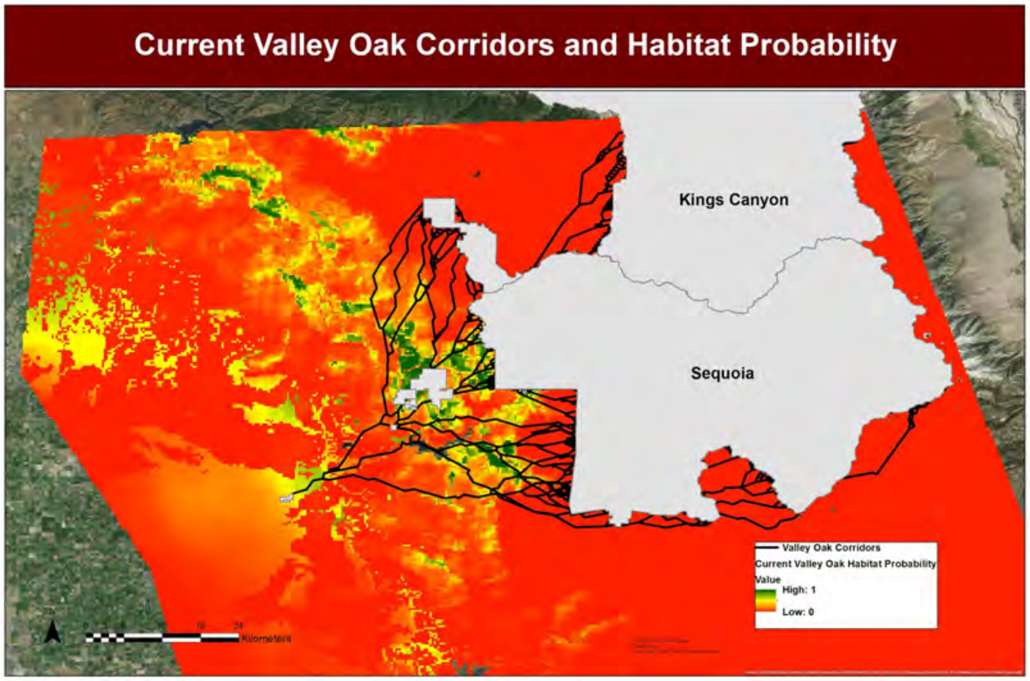

Figure 13: *Valley Oak least cost corridors displayed over MaxEnt habitat probability for current climate conditions.*

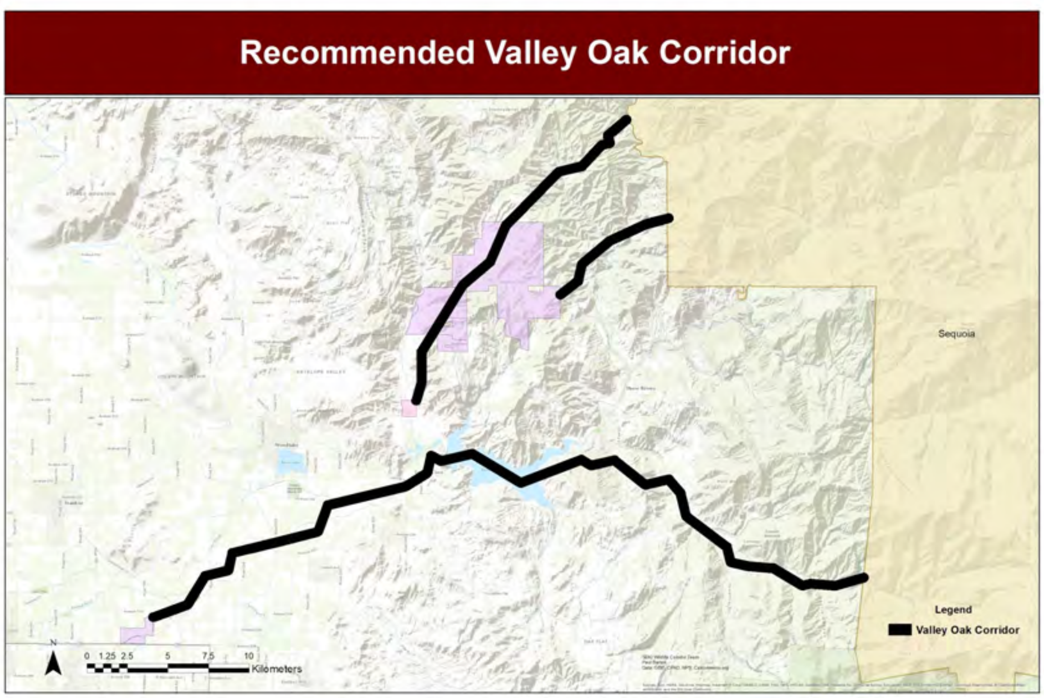

Figure 14: *Selected Valley Oak Corridors.*

Black Backed Woodpecker

The final corridor selection for the black-backed woodpecker is different than all other species. Although its original least cost corridor analysis yielded results similar to other species, showing additional potential paths heading north out of Dry Creek and east out of Kaweah Oaks, it's MaxEnt habitat probability model showed very low suitability for every region outside the parks, including in all future climate scenarios analysed (Figure 15, Appendix C). Thus, the selected woodpecker corridor is simply the shortest route that passes through the most protected lands: heading northeast through Homer Ranch and Mitigation Preserve then following the North Fork Kaweah River to the parks (Figure 16). Though there are limitations to our MaxEnt model, especially in regards to limited species presence data, according to our model we predict that the woodpecker will find use of a corridor through this region more difficult than other species will. Still, we believe the recommended corridors offer the best option.

The woodpecker's low habitat probability, even in less developed regions in the center of our study area, may be due to the lack of large trees and other vegetation necessary to maintain a population. Other than a few localized fragments in protected areas, the valley oak and other similar tree species are largely not found outside of the parks and the lands immediately surrounding it.

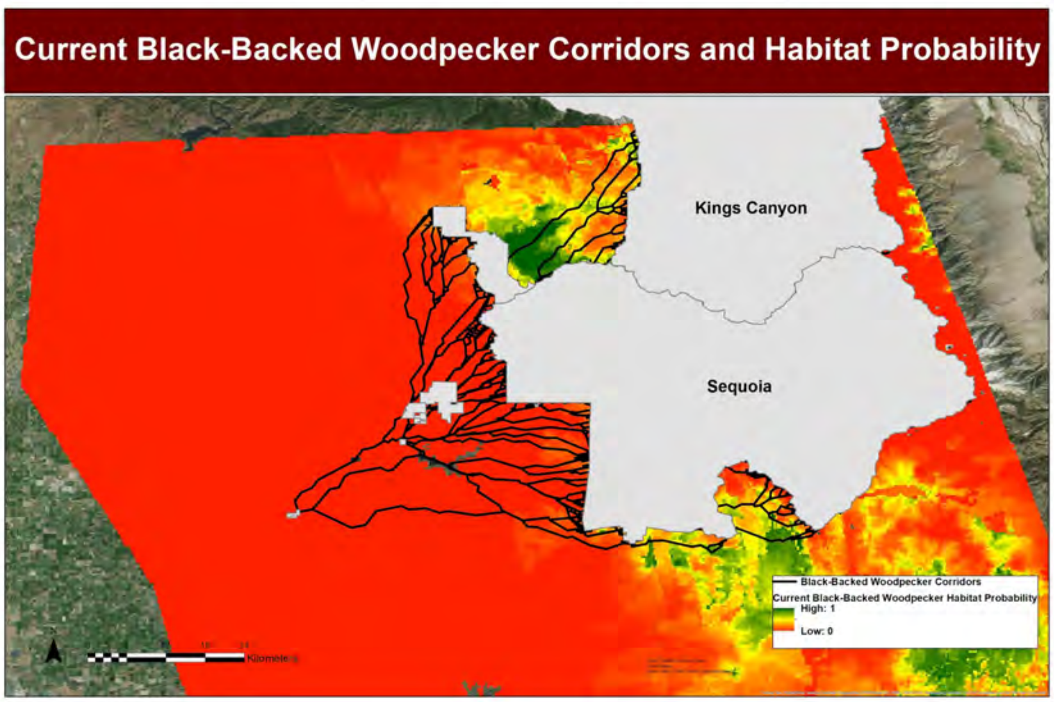

Figure 15: *Black-backed woodpecker least cost corridors displayed over MaxEnt habitat probability for current climate conditions.*

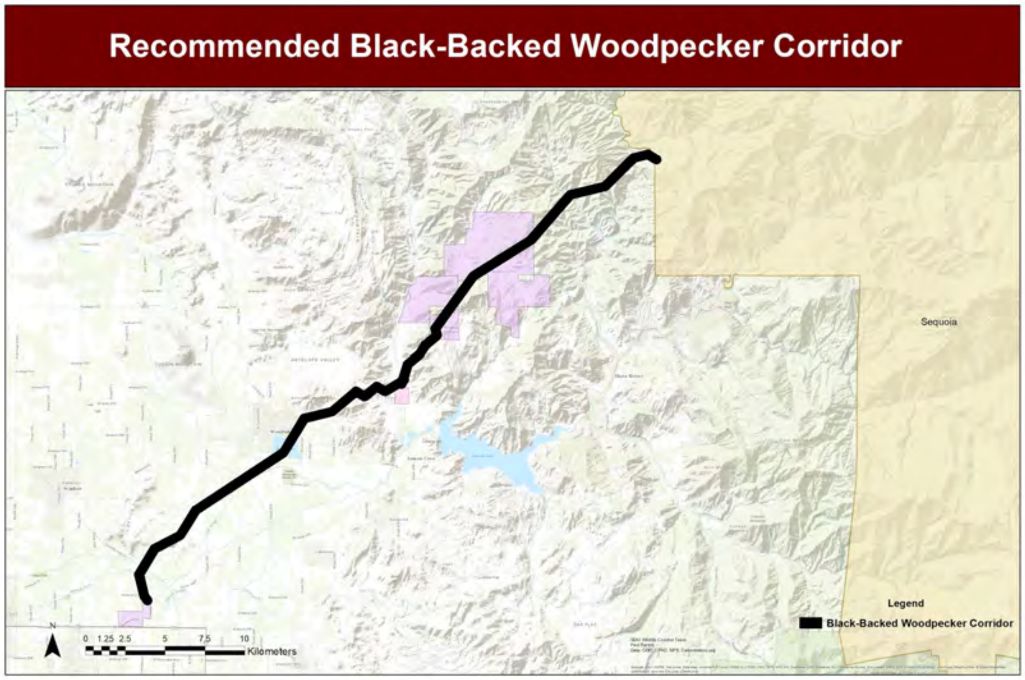

Figure 16: *Selected black-backed woodpecker corridor.*

Mule Deer

Mule Deer corridors and MaxEnt habitat probability is shown in Figure 16. One corridor extends from Kaweah Oaks and bifurcates into a northern and southern branch approximately two miles away from the reserve. Corridor options in the western region of the study area are limited as this region has low habitat probability for mule deer, primarily due to human influence, modeled in our analysis as road density and human population density. Mule deer are known to avoid areas that are highly altered due to human activity therefore the western region of the study site, which is highly affected by human development, provides very few options for mule deer corridors (Rost & Bailey 1979). As the northern branch approaches Dry Creek Reserve, a network of multiple corridors develops that terminate at the northwest border of Sequoia National Park and at Grant Grove in Kings Canyon National Park. One corridor in the northern branch, however, extending eastward from Dry Creek preserve, offers a different route to the south that ends up joining the southern branch extensions. From its starting place at Kaweah Oaks, the southern branch continues directly east as a single corridor for approximately twenty miles before radiating into many extensions that terminate at the southwest border of Sequoia National Park. The corridor network in the southern extension offers mule deer the most direct path to the park.

The MaxEnt model for Mule Deer led to its final corridor selection. Though other potential paths exist, the Southern region of our study area contains the most highly probable habitat outside the park, with almost no shift in habitat probability for mule deer over all three climate scenarios (Figure 17, Appendix C). The final selected corridors for mule deer were selected to reflect that, heading east from both Kaweah Oaks and Dry Creek Preserve into the park, with the latter following the South Fork Kaweah River (Figure 18).

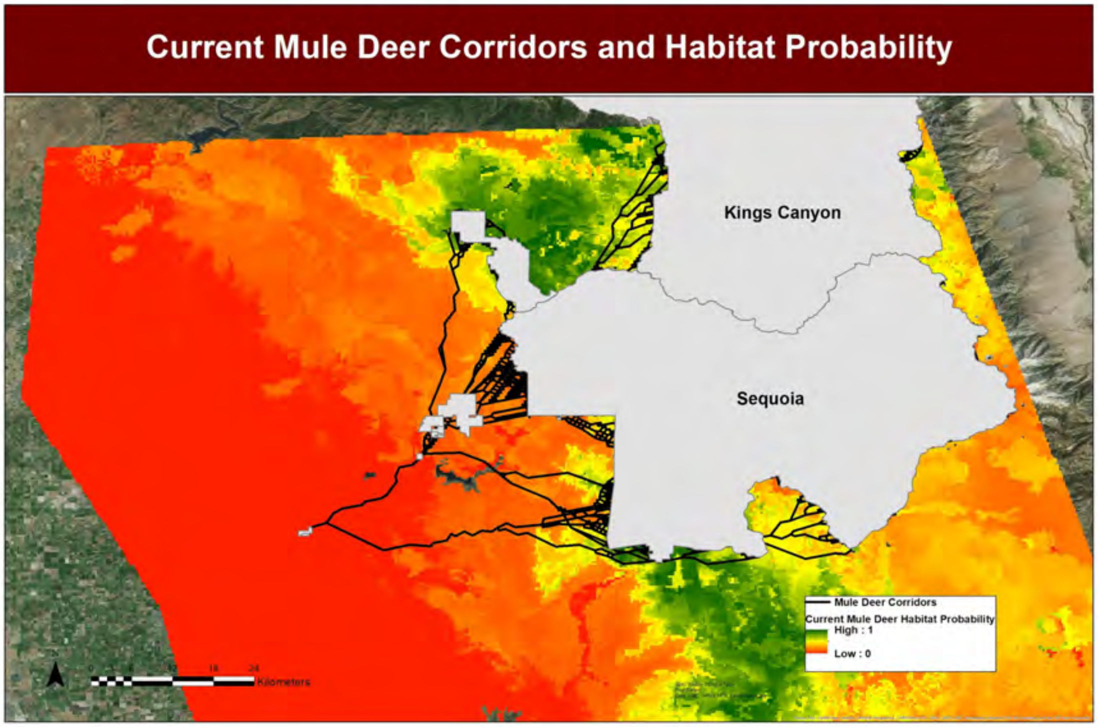

Figure 17: *Least cost paths overlaid on habitat probability for mule deer based on current climate conditions.*

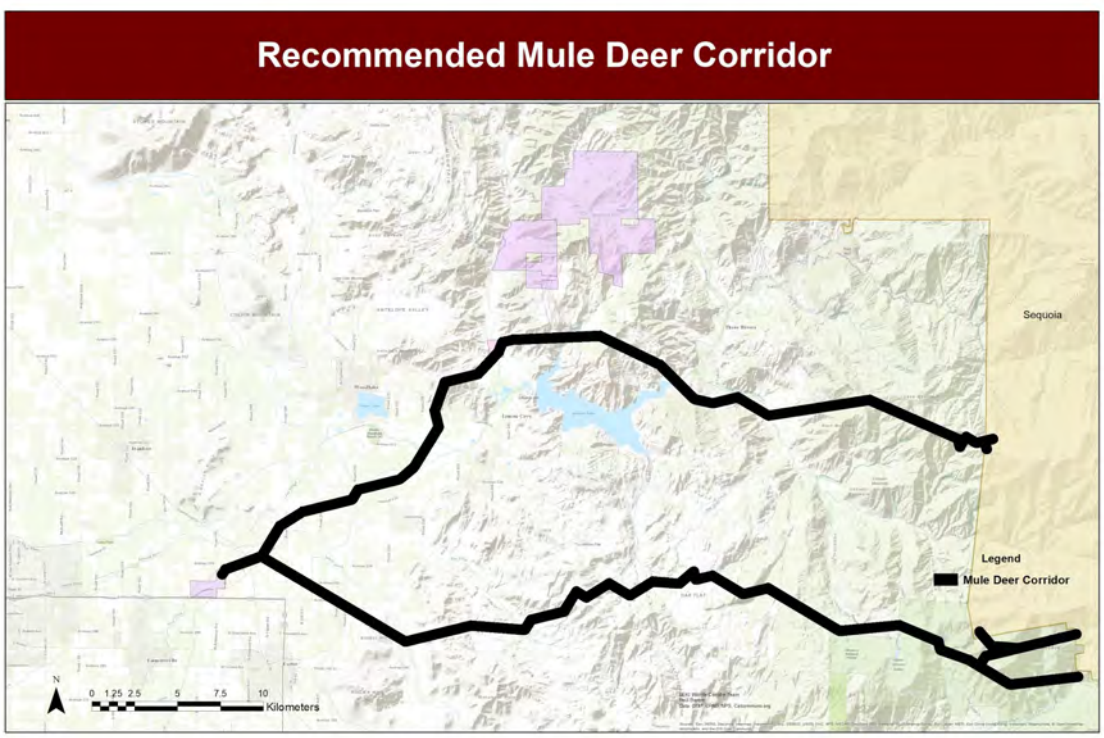

Figure 18: *Selected mule deer corridors.*

GENERAL CORRIDOR RESULTS

From our analysis of selected umbrella species, the four best corridors to pursue for the National Park Service are seen in black on Figure 19. Each corridor meets the criteria set forth in our methodologies section, follows a least cost path and livable habitat through two climate scenarios, and suits the needs of the largest number of the umbrella species possible. Since we ranked open water, which includes lakes and rivers, the lowest value for resistance (0), all the corridors follow a river for some part of their length, which is important because at least two of our species, the western pond turtle and valley oak, require some proximity to water.

All four of the identified corridors begin at Kaweah Oaks Preserve and follow relatively low development on the northern edge of the Kaweah River and just South of Bravo Lake. Two diverge before reaching the southern extent of Dry Creek Preserve and head due east to the southwestern border of the parks, passing through Lake Kaweah. The other two corridors split after crossing through Dry Creek Preserve and pass through both Homer Ranch and Mitigation Preserve. These two corridors head northeast and connect to the central-western edge of the parks. We have ranked the four options based on how many of the umbrella species they contain a viable path for and how short and direct a path they follow.

Corridor Option 1

This corridor is our favored recommendation. It is the most direct option and traverses the most protected land. The entire corridor overlaps our western fence lizard corridor and most of it overlaps our western pond turtle corridor, with just a small section of the turtle corridor diverging closer to Bravo Lake than our generalized Option 1 recommended corridor. Approximately half the corridor overlaps with the optimized valley oak corridor. In addition, the woodpecker corridor, which has almost no overlap with any other umbrella species, at least passes through the same general area as Option 1. In addition to being the most direct and shortest path to the park through protected lands, after passing through the southern edge of Mitigation Preserve, Corridor 1 loosely follows the North Fork Kaweah River through lightly-developed lands to the western edge of the park 4 km north of the latitudinal cut in the park's boundary. According to the habitat suitability models provided by MaxEnt, the gopher snake and western pond turtle have a high probability of living in Corridor 1 both presently and in the future. The section of the corridor between Mankins Creek and SEKI is also suitable for the western fence lizard and the section between Sheep Creek and SEKI is suitable for valley oak. In contrast, neither the black-backed woodpecker nor mule deer have high suitability probability for this option. However, this corridor accommodates the largest number of species and also covers the least amount of parcel according to Tulare County's zoning data. This is important as it could reduce the amount of easements the National Park Service would need to negotiate in order to acquire land for this corridor.

Corridor Option 2

The next corridor option that the Park Service should pursue is labeled Option 2 on Figure 19. This corridor actually has slightly more overlap with our focal species, but is longer than Option 1 and unlike Option 1, does not have the benefit of passing through Homer Ranch and Mitigation Preserve. However, both Option 1 and 2 are highly recommended. Western fence lizard, valley oak, and western pond turtle all will be supported by Option 2 according to our corridor analysis. The corridor likely provides the best habitat for our umbrella species, as it contains the most riverlands. It leaves Dry Creek heading southeast, passing north of Kaweah Lake. It crosses CA 198 then closely follows the South Fork Kaweah River all the way to the park. According to MaxEnt, the area covered by this corridor shows a high probability of habitat for fence lizard, gopher snake, western pond turtle, and valley oak both presently and in the future. While our MaxEnt analysis shows very little area of suitability for woodpeckers, this corridor is nevertheless the most suitable of the four. This corridor is ranked lower than Option 1 almost solely due to its longer length, which is problematic primarily because it as a result likely covers more individual land parcels. However, this corridor is still very viable; it suits the needs of the highest number of our umbrella species and provides habitat from now and into the future.

Corridor Option 3

The third corridor option the Park Service should pursue is marked as Option 3 on Figure 19. This corridor still has a large amount of intersect between our focal species that would make it a good option to pursue; however, it is not the best option as it is longer than Option 1 and optimal for fewer species than Option 2. Option 3 is best for gopher snake and mule deer, with our lizard corridor overlapping about half of the generalized corridor. Corridor 3 follows the same path at Corridor 2 after leaving Dry Creek, but splits off 5.5 km park-wards, taking a more direct route due east over lightly-developed lands into the parks. Our MaxEnt results show that the corridor would follow high habitat suitability for mule deer and fence lizard. While it has the highest probability for deer habitat by far, it also has easily the least probability for pond turtle habitat. This corridor is still a strong option, but contains less riverland habitat than Option 2 and covers fewer umbrella species.

Corridor Option 4

The fourth corridor option the Park Service could pursue is marked as Option 4 on Figure 19. This corridor still has a large amount of intersect between our focal species that would make it a good option to pursue; however is not the best option as it only overlaps with two of our umbrella species: gopher snake and valley oak. However, corridor options for the black-backed woodpecker are also in the general vicinity of Corridor 4 and it passes through all four of the nature preserves in the study area. Corridor 4 travels northeast, along with Corridor 1, and passes through both Homer Ranch and Mitigation Preserve, crossing over foothills to connect to the Park along the North Fork Kaweah River. Our MaxEnt results show that the corridor would follow high habitat suitability for valley oak as well as for western pond turtle. This corridor is a viable option, but is a longer pathway than Corridor 1, despite passing through more protected lands.

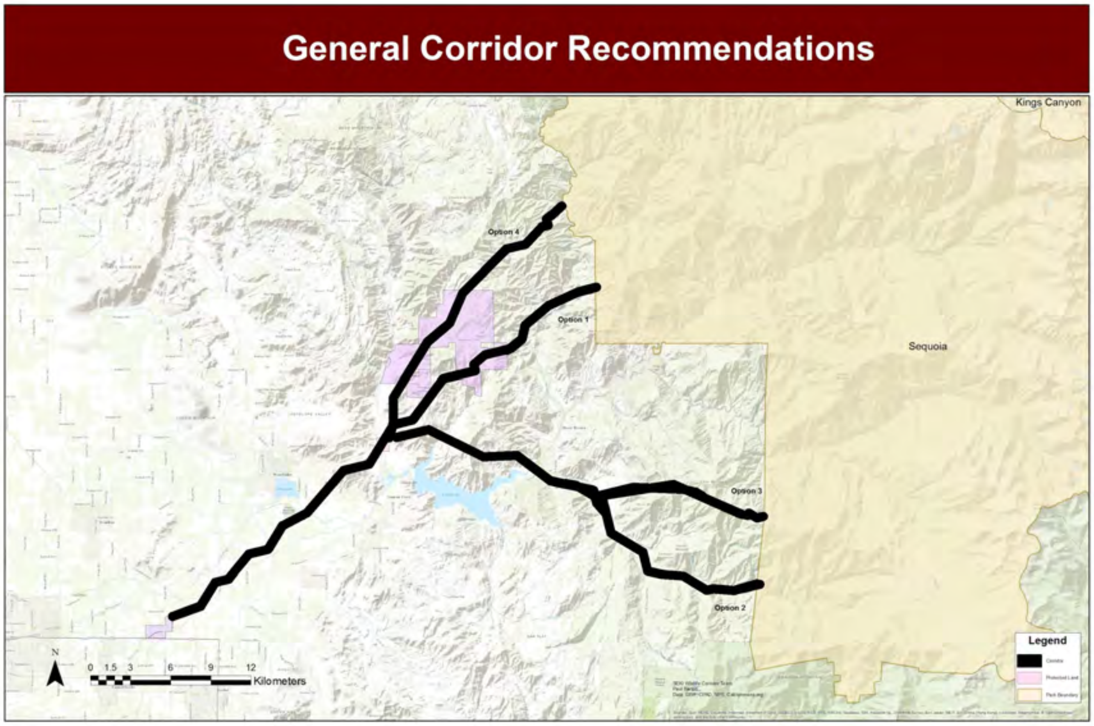

__Figure 19:__ General Corridors based on shortest distance from protected lands and most umbrella species utilized.

Recommendations for Further Action

Legal Options for Establishing Wildlife Corridors

Wildlife corridors are often established through creation of an easement, wherein a parcel of land is either sold or donated by a landowner to a public agency or private organization, such as a conservation group, often for conservation purposes. This is typically a permanent, legally binding agreement that limits the rights the landowner and the agency or conservation group have over use the land, while retaining private ownership (Nature Conservancy 2016). The ultimate role of an easement is to protect traditional land uses, but it can be tailored to fit the exact needs of the land, the landowner, and the agency or organization holding the easement. By 2000, 2.6 million acres of land in the United States had been protected by easements, a number that continues to grow (*Id*). Easements can be beneficial to landowners because they receive tax breaks to offset the loss of property value and can be developed to allow for continued use of the land for agriculture, livestock grazing, and minor development, while supporting conservation (The Land Trust Alliance 2016).

Limitations of the Research

Focal Species Selection

When designing wildlife corridors, target species are often selected from various taxonomic groups and serve as a proxy for other species in the community with similar requirements (Fry et al. 1986). This species-specific design assumes that species within the same trophic level are equivalent and will not only share equivalent resources but will also behave equivalently (Hubbell 2005). However, this assumption is false. For example, among carnivorous species, response to fragmentation differs drastically as some are more tolerant to urbanization than others (Crook 2002). For this study, the focal species list is limited in that it does not include a small mammal or a predator. These decisions were based on expert opinion that small mammals in the study region may not utilize a wildlife corridor, as they are predicted to migrate latitudinally rather than up in elevation, and that predator migration follows prey migration.

Starting Point Selection - Western Fence Lizard

All of our corridors, species specific or general, with one exception begin at either Dry Creek or Kaweah Oaks Preserve. These locations serve as suitable starting points as they are isolated sections of relatively natural habitat despite not overlapping with the focal species hotspots, or areas of high concentration. Most of our focal species hotspots lie within the park so would not have been able to serve as a starting location, except for a hotspot for the western fence lizard. A lizard hotspot lies to the northeast of Kaweah Oaks, so it could have served as another starting location for their corridor analysis. We chose to not include the hotspot as a starting point for one of our recommended corridors, however, because of the time constraints of the project.

Presence vs. Absence Data

Data limitation also affected the results of the least cost path. Species presence data was collected for our focal species primarily from the Global Biodiversity Information Facility. Valley oak presence data was the lone exception; it was acquired from the Conservation Biology Institute. The combined presence data, however, is not representative of the entire populations of the target species in the study site. Presence data is limited by observation and thus areas with higher population densities may experience bias in terms of higher frequencies of observation. This can falsely show that species exist more frequently in dense areas and thus prefer that habitat. Working within the scale of our project, it is impractical to acquire complete quantitative data on species populations in the study area. Although it is possible to know which parts of the study area are potentially good habitat for different species, the probability that a focal species actually occurs in that area is uncertain. In order to overcome the lack of information on species populations in the study site, it is assumed that an individual may occur any place where habitat suitability for the species is the highest among the surrounding. If absence data were collected instead for the focal species in the study area, it would allow for a better understanding of species occurrence in the study site.

Limited Data for MaxEnt

Ryan Harrigan of UCLA, an expert in MaxEnt habitat probability modeling, recommended we use at least 20 species presence points for MaxEnt to run correctly. We were able to surpass this threshold for all species except the western pond turtle. In addition, several species were closer to the threshold of 20 presence points than others, which may lower the effectiveness of comparing MaxEnt models between species. The western pond turtle had 12 data points, gopher snake had 24, black-backed woodpecker had 28, valley oak had 37, mule deer had 68, and western fence lizard had 249.

Interpretation of Cost

In the least cost approach, resistance explains a species' tendency to avoid a particular area and is quantified by assigning a resistance value. However, there are no set values for the magnitude of cost to a species, as this is difficult to quantify. Instead, the values that were assigned in this study were based on informed predictions and expert opinion. The relative weight for each type of resistance and the resistance values themselves may be subject to debate. Also, there may be other resistance inputs that have a significant impact on one or more of our focal species that were not included in the model. Due to the time constraints of the project, target species were assigned the same resistance values. In doing so, all six species were assumed to require the same habitat type and respond similarly to resistance. This assumption is false as there are niche differences among our focal species but, because they are generalist species in the foothill region, this assumption serves as a good approximation. We compensated for this assumption by weighting each variable differently for each species based on behavior data.

Species Behavior

Because different organisms perceive and respond to changes in landscape patterns and processes differently, it is impossible to model species behavior in response to climate change. While this study models habitat suitability, habitat connectivity, and predicted variations in the landscape due to climate change, there is no guarantee that species will use it to move up in elevation even if the conditions in the corridor are ideal. One expert, Dr. Brian Cypher of California State Stanislaus, predicts that as the foothill regions become increasingly stressed due to climate change, valley floor mammals may migrate north in latitude rather than up in elevation. Ultimately, animal behavior is variable and difficult to model which makes it one of the greatest limitations of our study.

Conclusion

Climate change poses a serious risk to ecosystem health in the Kaweah Watershed and more generally the San Joaquin Valley, a region already adversely affected by human development and agriculture. Many species in this region are only able to survive in the few remaining habitat fragments left relatively untouched, and will have nowhere to go when rising temperatures threaten this remaining habitat. Providing these species with stable paths to climate refuges such as the protected lands and large elevational gradient of Sequoia and Kings Canyon National Parks could greatly mitigate the impacts of climate change. The wildlife corridors we recommend are based on the needs of generalist species, and as such represent safe corridors for a large variety of plants and animals. Initial analysis performed for these corridors included a variety of species-specific movement factors, land use, slope, road density, and human population density, to create least cost paths using ArcGIS. These least cost paths show many options an individual might take from one of the managed preserves, or habitat fragments, to SEKI, but presented too many options, did not factor in climate change, and did not take into account the ability of a species to live within a corridor, not just pass through it, which is important for species that may take many generations to cross a corridor such as the western pond turtle and the valley oak. We were able to remedy all three of these issues by choosing our final corridors based on MaxEnt habitat probability models created for each target species using present climate data and two future scenarios in the GFDL 2.1 A2 climate model, 2040-2069 and

2070-2099. Corridors were then selected based on how well they followed highly-suitable habitat and how well their pathway habitat stood up to changing climate. The final corridors were buffered 250 meters and overlapped to define four final corridors that will protect the highest number of species from incoming climate change.

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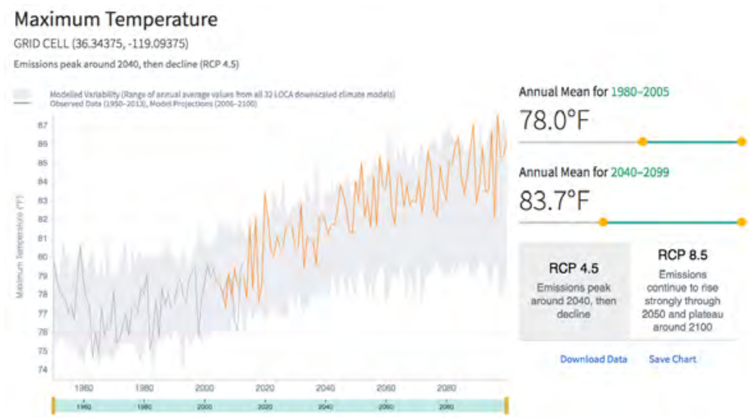
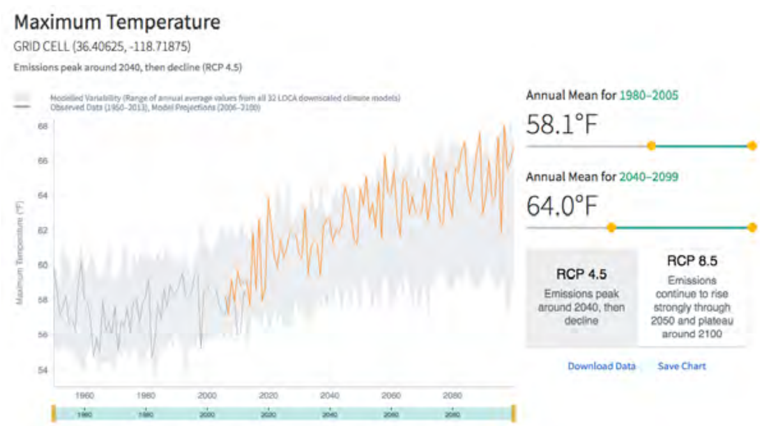
Appendix

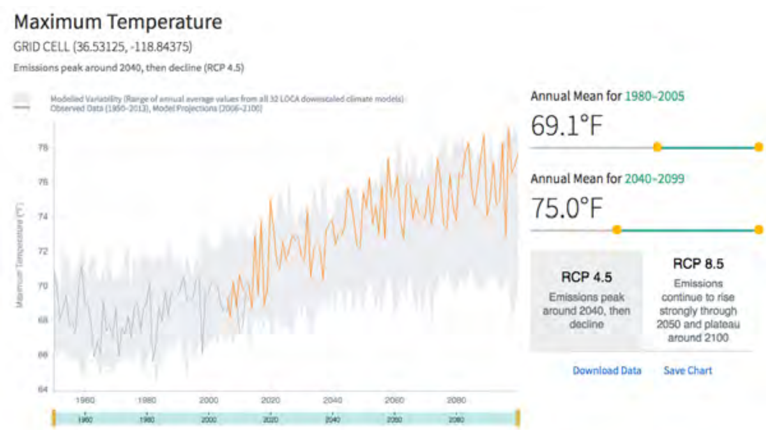
Appendix A: Climate Change Data



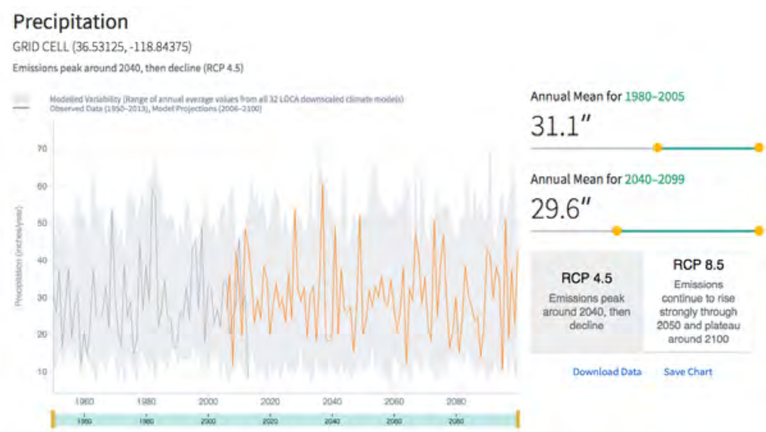
Appendix 1: Average maximum temperatures at starting point between 1950 and 2100 with ranges shown between (1980 - 2005) and (2040 - 2099) (CalAdapt)



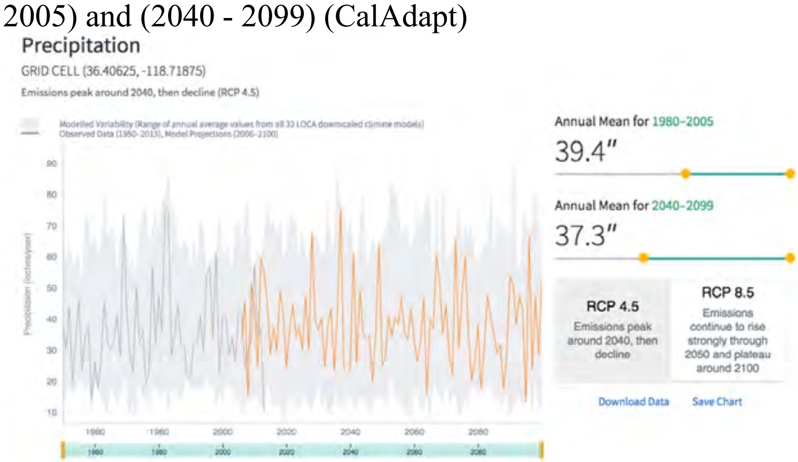
Appendix 2: Average maximum temperatures at potential corridor exit 1 between 1950 and 2100 with averages between (1980 - 2005) and (2040 - 2099) shown (CalAdapt)



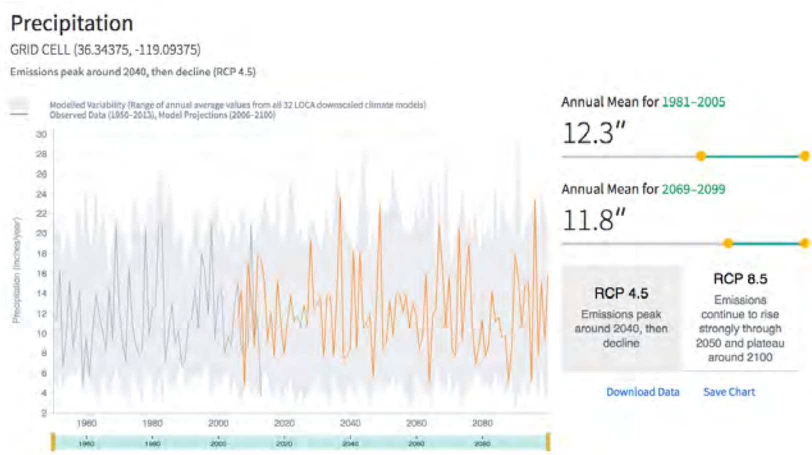
Appendix 3: Average maximum temperatures at potential corridor exit 2 between 1950 and 2100 with ranges shown between (1980 - 2005) and (2040 - 2099) (CalAdapt)



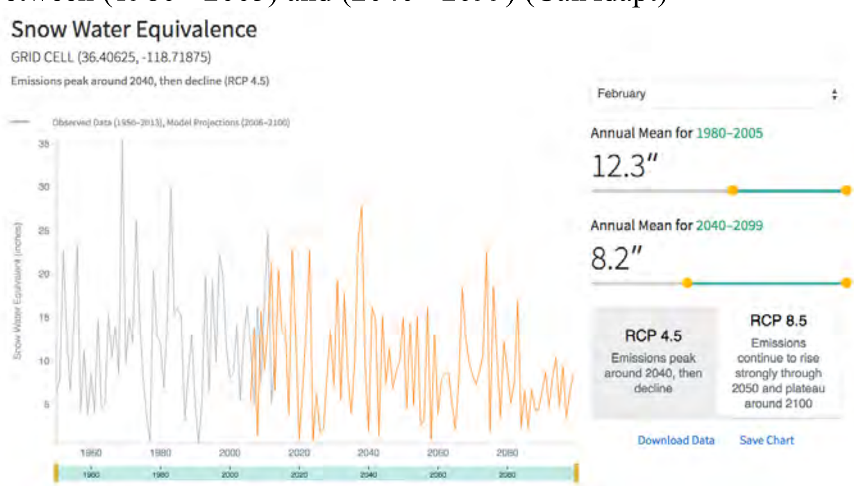
Appendix 4: Average Precipitation at starting point between 1950 and 2100 with ranges shown between (1980 - 2005) and (2040 - 2099) (CalAdapt)



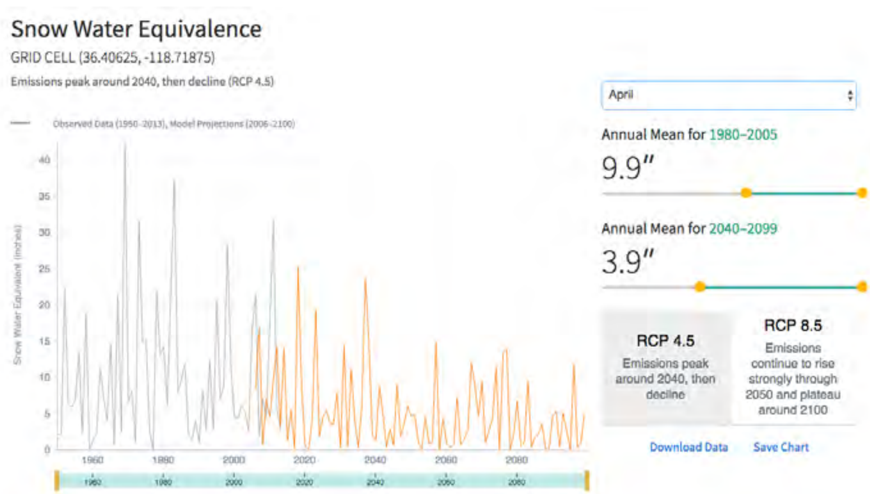
Appendix 5: Average Precipitation at potential corridor exit 1 between 1950 and 2100 with ranges shown between (1980 - 2005) and (2040 - 2099) (CalAdapt)



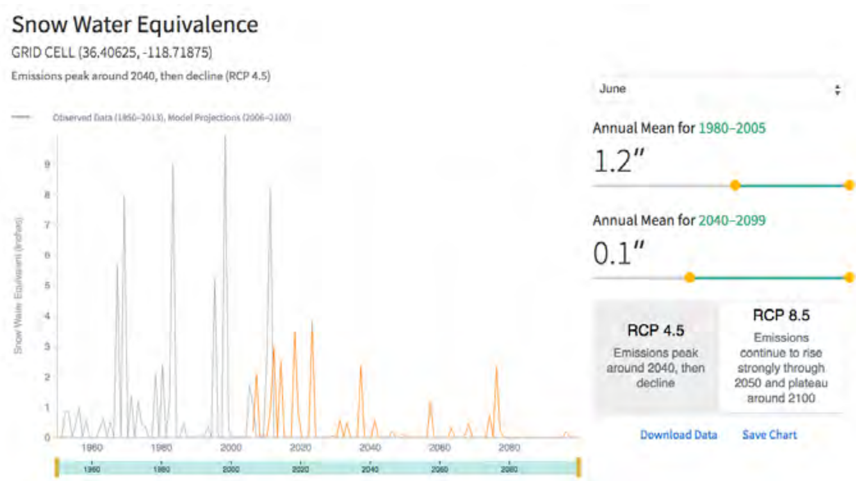
Appendix 6: Average Precipitation at potential corridor exit 2 between 1950 and 2100 with ranges shown between (1980 - 2005) and (2040 - 2099) (CalAdapt)



Appendix 7: Average February snow water equivalence at potential corridor exit 1 (2A) between 1950 and 2100 with ranges shown between (1980 - 2005) and (2040 - 2099) (CalAdapt)



Appendix 8: Average April snow water equivalence at potential corridor exit 1 (2A) between 1950 and 2100 with ranges shown between (1980 - 2005) and (2040 - 2099) (CalAdapt)



Appendix 9: Average June snow water equivalence at potential corridor exit 1 (2A) between 1950 and 2100 with ranges shown between (1980 - 2005) and (2040 - 2099) (CalAdapt)

Appendix B: Methodology and Data Collection

Vegetation Type/ Land Use	Resistance Values
California Central Valley Mixed Oak Savanna	1
California Lower Montane Blue Oak-Foothill Pine Woodland and Savanna	1
Mediterranean California Mixed Oak Woodland	1
California Montane Jeffrey Pine-(Ponderosa Pine) Woodland	1
Great Basin Foothill and Lower Montane Riparian Woodland and Shrubland	1
California Central Valley Riparian Woodland and Shrubland	1
Mediterranean California Foothill and Lower Montane Riparian Woodland	1
North American Warm Desert Riparian Woodland and Shrubland	1
California Montane Woodland and Chaparral	1
Temperate Pacific Freshwater Emergent Marsh	1
Temperate Pacific Montane Wet Meadow	1
Open Water (Fresh)	1
Mediterranean California Dry-Mesic Mixed Conifer Forest and Woodland	2
Mediterranean California Mesic Mixed Conifer Forest and Woodland	2
Sierran-Intermontane Desert Western White Pine-White Fir Woodland	2
Mediterranean California Red Fir Forest	2
Mediterranean California Subalpine Woodland	3
Northern California Mesic Subalpine Woodland	3
Sierra Nevada Subalpine Lodgepole Pine Forest and Woodland	3
California Mesic Chaparral	3
Northern and Central California Dry-Mesic Chaparral	3
California Central Valley and Southern Coastal Grassland	3
North Pacific Montane Grassland	3
North American Arid West Emergent Marsh	3
Great Basin Xeric Mixed Sagebrush Shrubland	3
Inter-Mountain Basins Big Sagebrush Shrubland	3
Inter-Mountain Basins Semi-Desert Grassland	3
Harvested Forest-Shrub Regeneration	3
Harvested Forest - Northwestern Conifer Regeneration	3

Inter-Mountain Basins Subalpine Limber-Bristlecone Pine Woodland	4
Rocky Mountain Aspen Forest and Woodland	4
Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland	4
Rocky Mountain Subalpine Mesic Spruce-Fir Forest and Woodland	4
Inter-Mountain Basins Juniper Savanna	4
Inter-Mountain Basins Greasewood Flat	4
Inter-Mountain Basins Playa	4
Inter-Mountain Basins Big Sagebrush Steppe	4
Inter-Mountain Basins Montane Sagebrush Steppe	4
Inter-Mountain Basins Semi-Desert Shrub Steppe	4
Inter-Mountain Basins Shale Badland	4
Mediterranean California Alpine Bedrock and Scree	4
Recently burned grassland	4
Recently burned forest	4
North Pacific Wooded Volcanic Flowage	5
Great Basin Pinyon-Juniper Woodland	5
Inter-Mountain Basins Curl-leaf Mountain Mahogany Woodland and Shrubland	5
Great Basin Semi-Desert Chaparral	5
North American Warm Desert Bedrock Cliff and Outcrop	5
North American Warm Desert Volcanic Rockland	5
North American Warm Desert Playa	6
Mojave Mid-Elevation Mixed Desert Scrub	6
North American Warm Desert Active and Stabilized Dune	6
Sonora-Mojave Creosotebush-White Bursage Desert Scrub	6
Sonora-Mojave Mixed Salt Desert Scrub	6
North American Warm Desert Wash	6
Inter-Mountain Basins Mixed Salt Desert Scrub	6
North American Warm Desert Pavement	6
Sierra Nevada Cliff and Canyon	7
Inter-Mountain Basins Cliff and Canyon	7
Cultivated Cropland	7
Pasture/Hay	7

North Pacific Active Volcanic Rock and Cinder Land	8
Developed, Open Space	8
Developed, Low Intensity	8
Developed, Medium Intensity	10
Developed, High Intensity	10

Table 2: Table of assigned resistance values for vegetation type/ land use.

Slope	Resistance Values
0 -10	1
10 - 20	3
20 - 40	5
>40	7

Table 3: Resistance Values for Slope

Road Density	Resistance Values
0 -0.5	1
0.5 - 1	1
1 - 2	2
2 - 4	5
4 - 6	7
6 - 10	8
>10	10

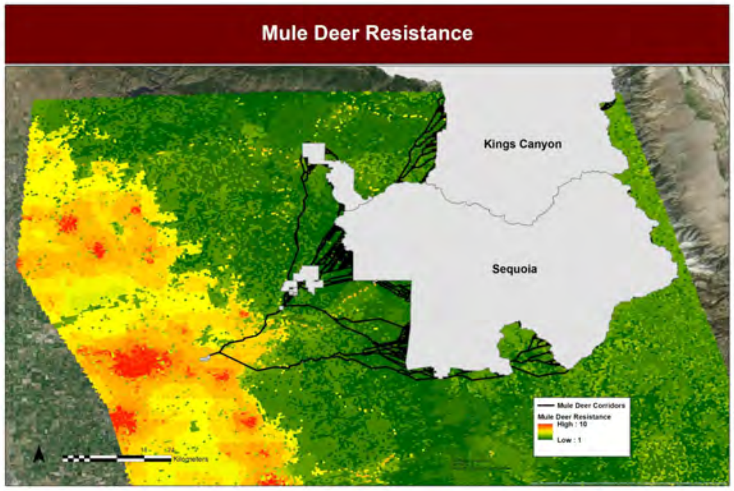
Table 4: Road Density Resistance Values

Population Density (people per square mile)	Resistance Values
0 - 10	1
10 - 25	2
25 - 50	3
50 - 100	4
100 - 1000	6
1000 - 5000	8
5000 - 160000	10

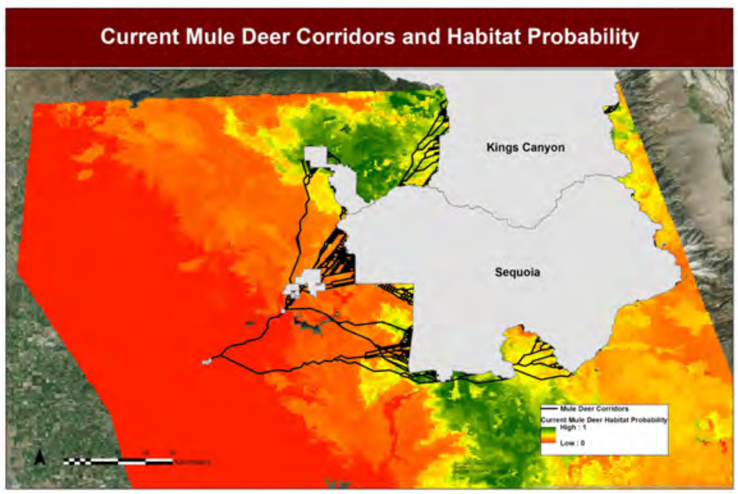
Table 5: Population Density Resistance Values

Appendix C: Species-Specific Climate Change Habitat Probability

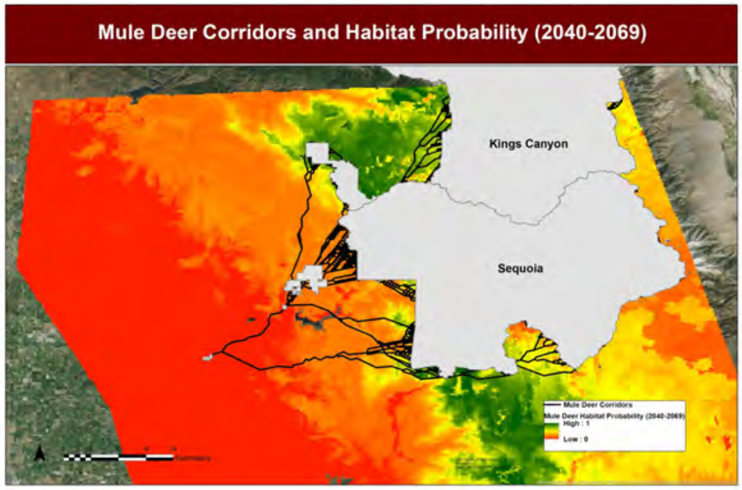
Mule Deer



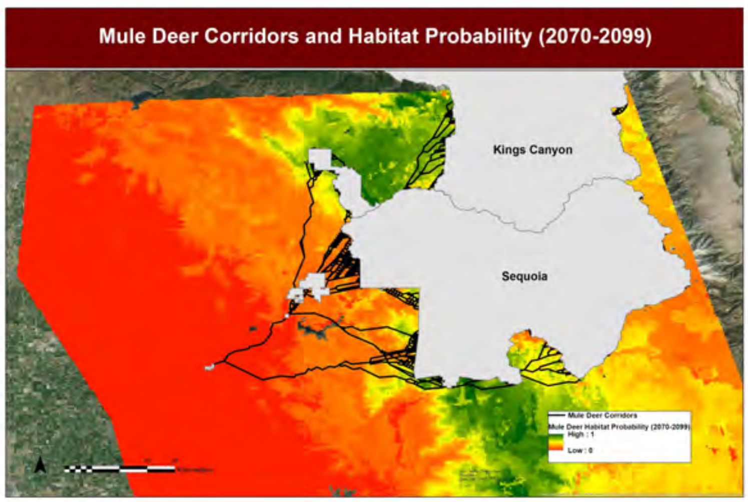
Appendix 10: Least cost paths overlaid on resistance for the mule deer



Appendix 11: Least cost paths overlaid on the MaxEnt output of current climate data for the mule deer

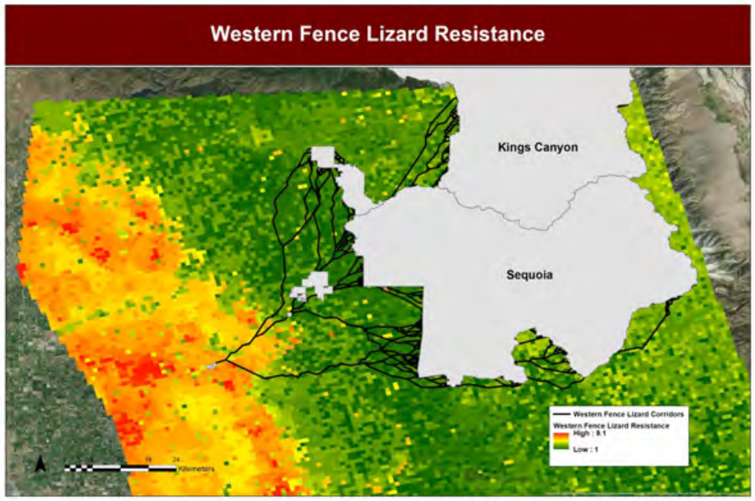


Appendix 12: Least cost paths overlaid on the MaxEnt output of 2040-2069 climate data for the mule deer.

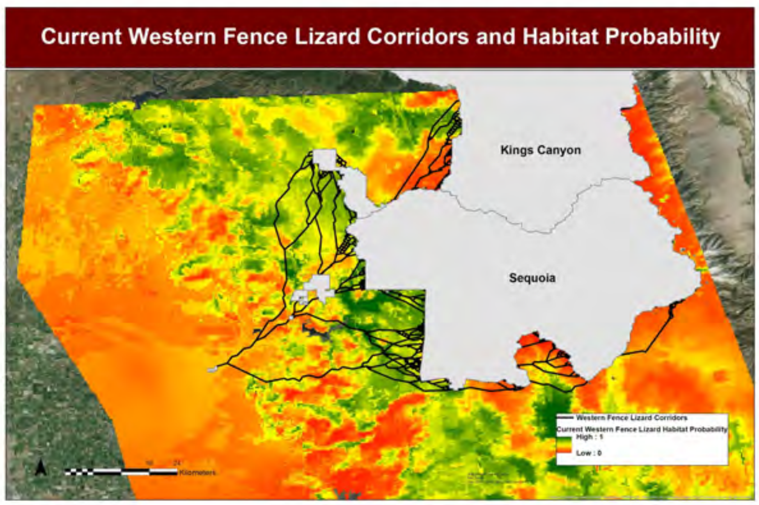


Appendix 13: Least cost paths overlaid on the MaxEnt output of 2070-2099 climate data for the mule deer.

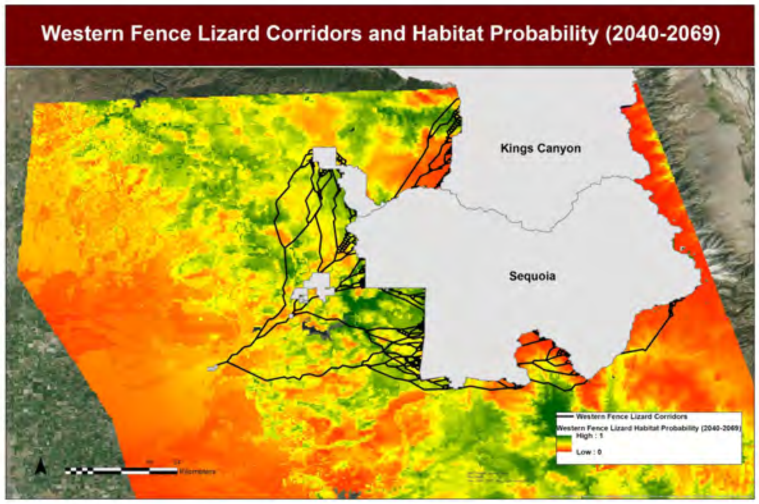
Western Fence Lizard



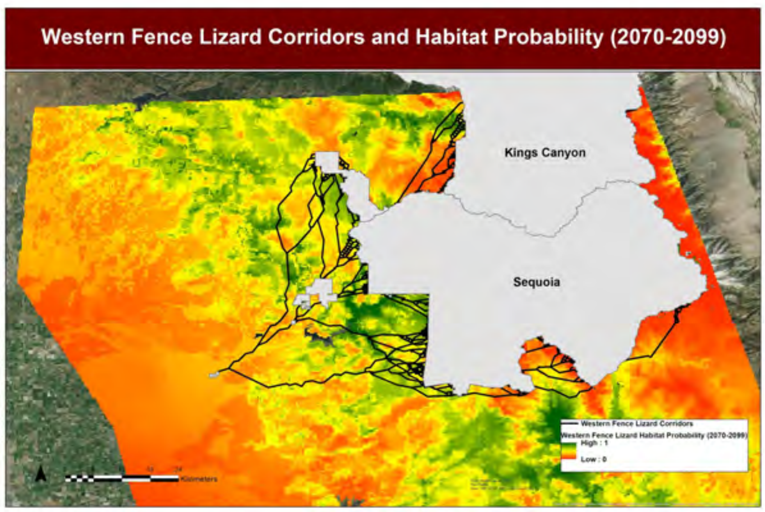
Appendix 14: Least cost paths overlaid on resistance for the western fence lizard



Appendix 15: Least cost paths overlaid on the MaxEnt output of current climate data for the western fence lizard

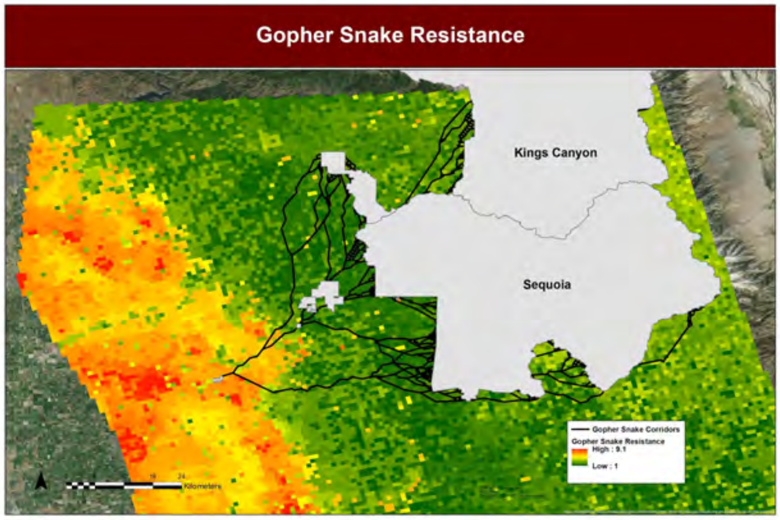


Appendix 16: Least cost paths overlaid on the MaxEnt output of 2040-2069 climate data for the western fence lizard

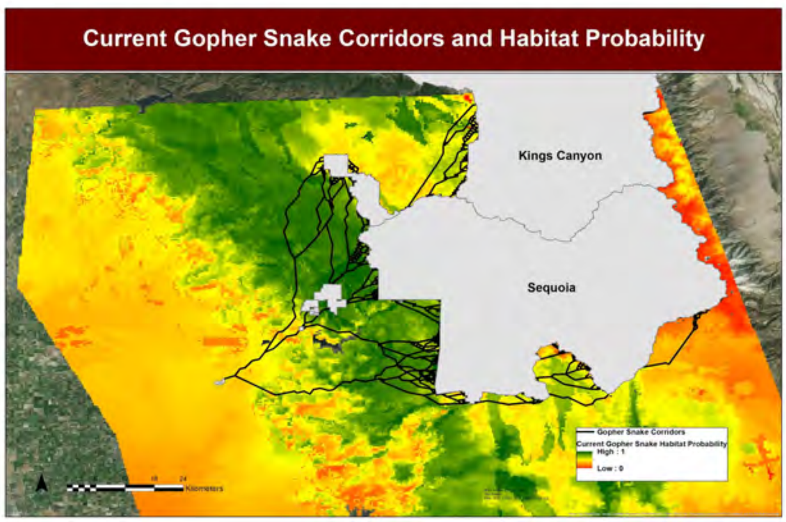


Appendix 17: Least cost paths overlaid on the MaxEnt output of 2070-2099 climate data for the western fence lizard

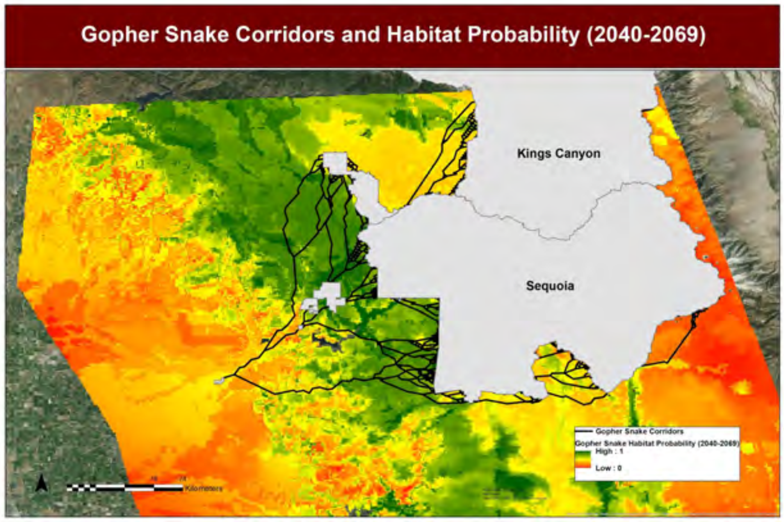
Gopher Snake



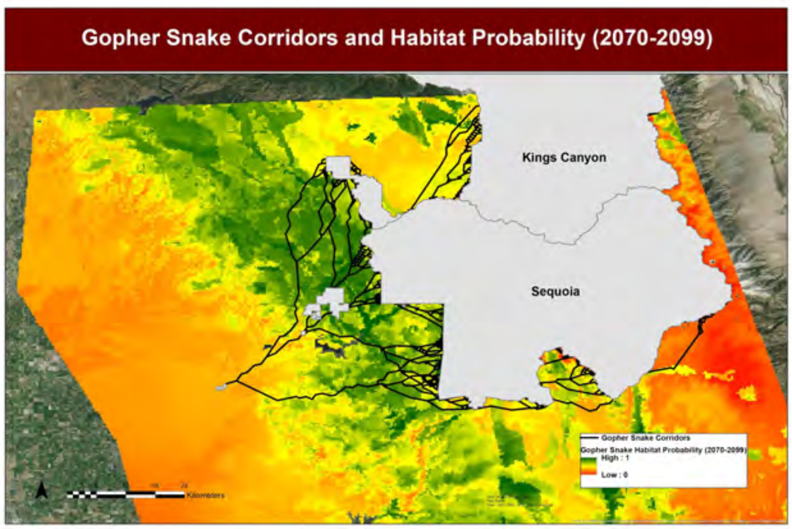
Appendix 18: Least cost paths overlaid on resistance for the gopher snake



Appendix 19: Least cost paths overlaid on the MaxEnt output of current climate data for the gopher snake

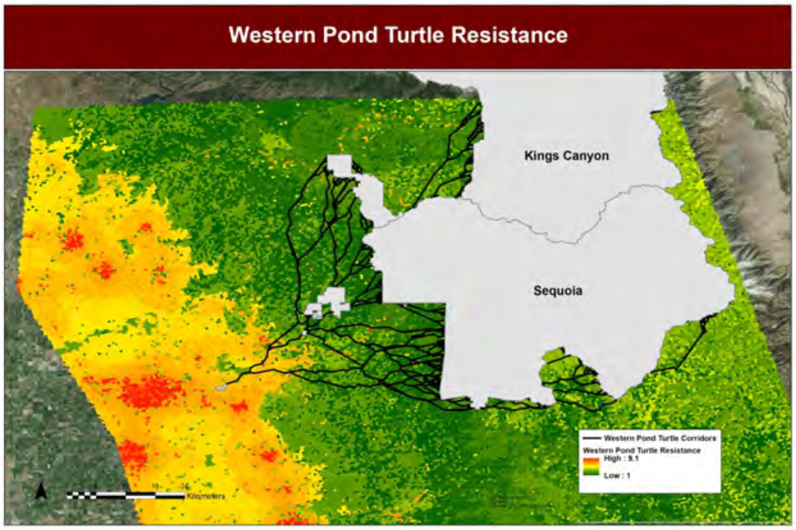


Appendix 20: Least cost paths overlaid on the MaxEnt output of 2040-2069 climate data for the gopher snake

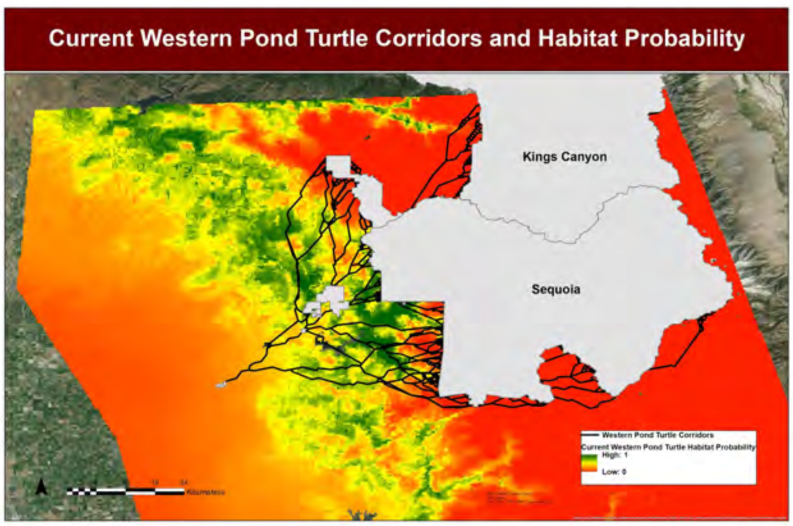


Appendix 21: Least cost paths overlaid on the MaxEnt output of 2070-2099 climate data for the gopher snake

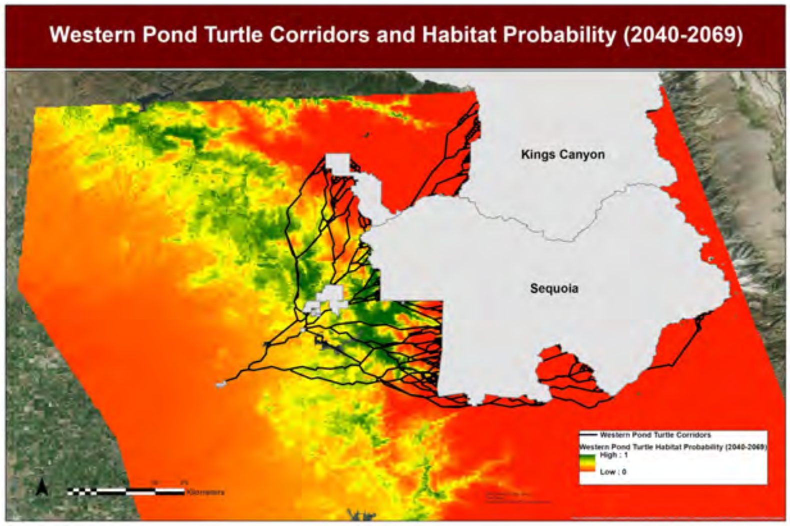
Western Pond Turtle



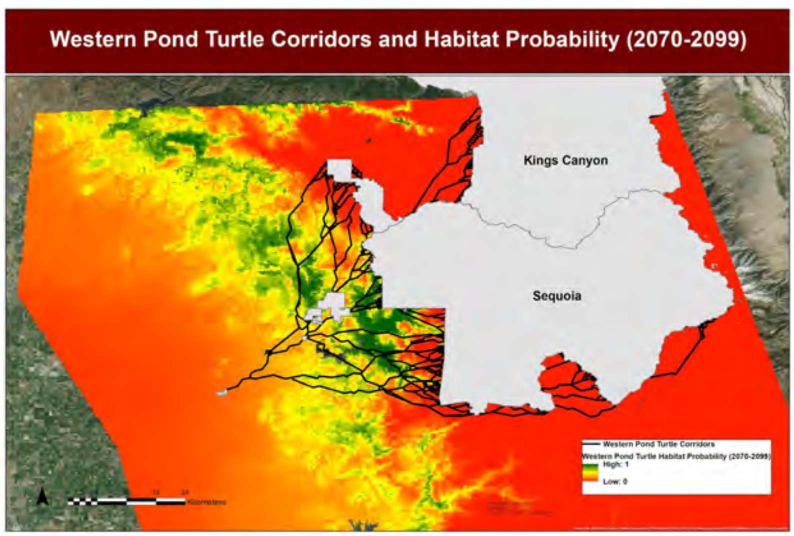
Appendix 22: Least cost paths overlaid on resistance for the western pond turtle



Appendix 23: Least cost paths overlaid on the MaxEnt output of current climate data for the western pond turtle

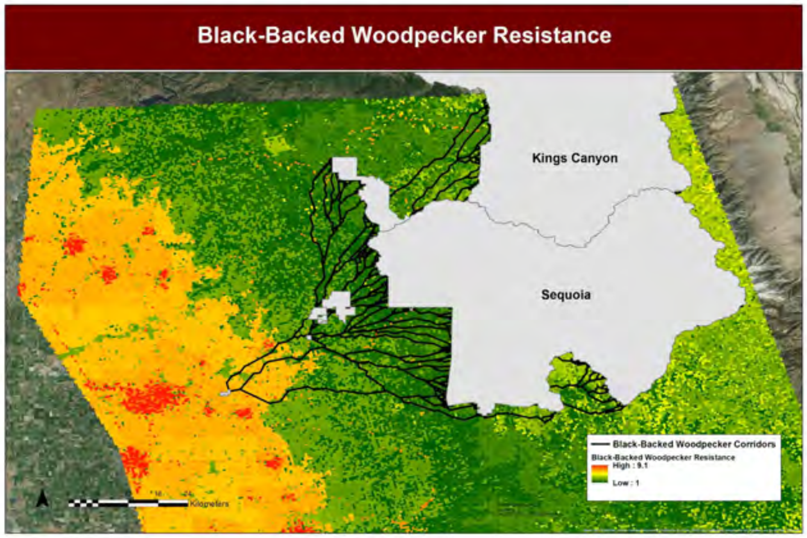


Appendix 24: Least cost paths overlaid on the MaxEnt output of 2040-2069 climate data for the western pond turtle

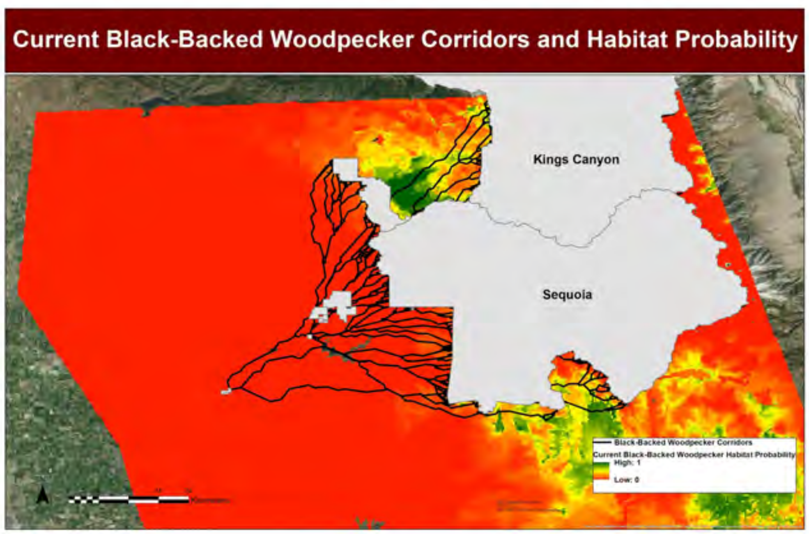


Appendix 25: Least cost paths overlaid on the MaxEnt output of 2070-2099 climate data for the western pond turtle

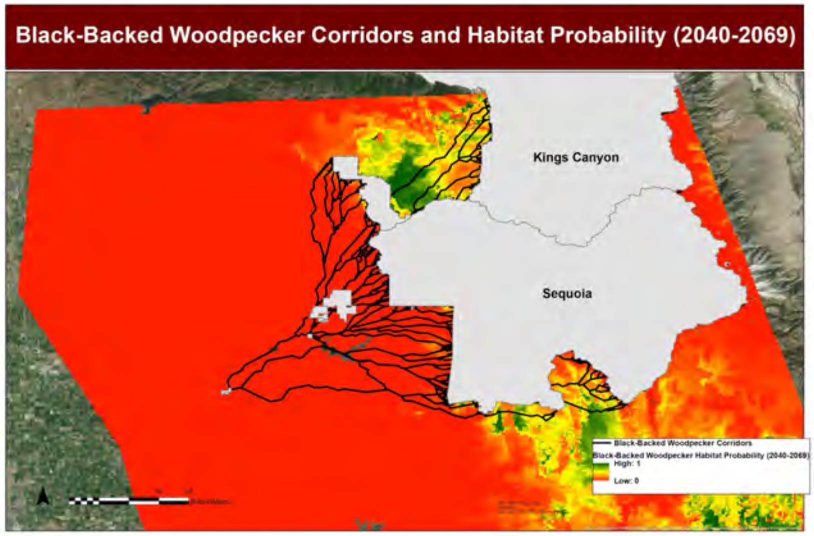
Black-Backed Woodpecker



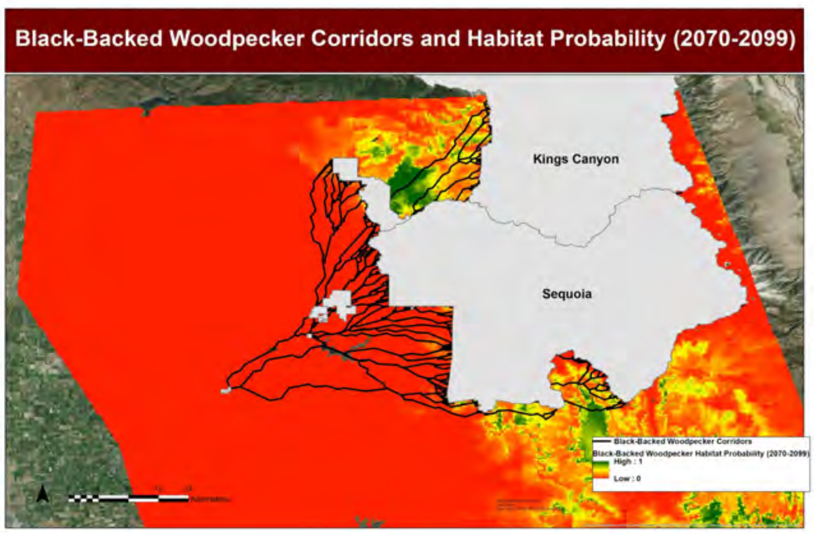
Appendix 26: Least cost paths overlaid on resistance for the black-backed woodpecker



Appendix 27: Least cost paths overlaid on the MaxEnt output of current climate data for the black-backed woodpecker

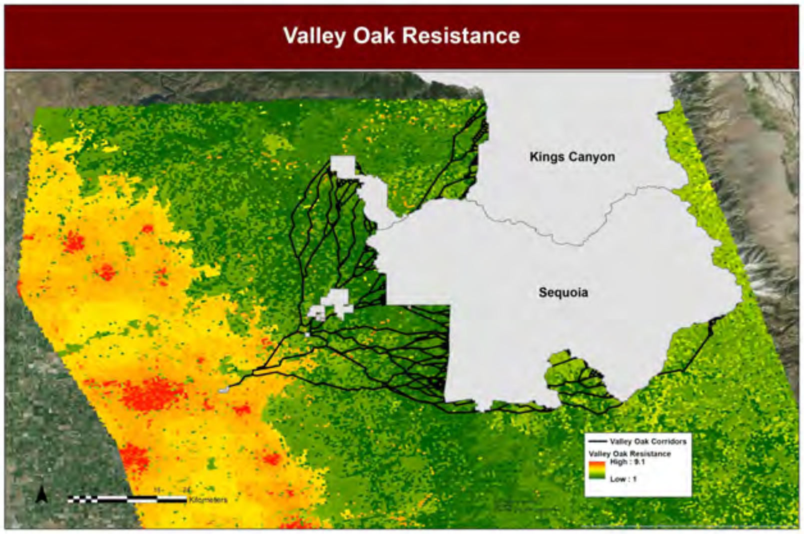


Appendix 28: Least cost paths overlaid on the MaxEnt output of 2040-2069 climate data for the black-backed woodpecker

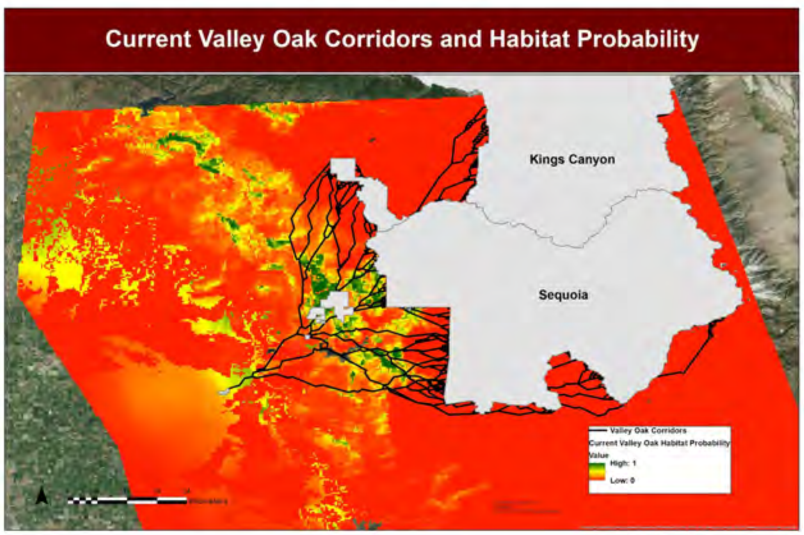


Appendix 29: Least cost paths overlaid on the MaxEnt output of 2070-2099 climate data for the black-backed woodpecker

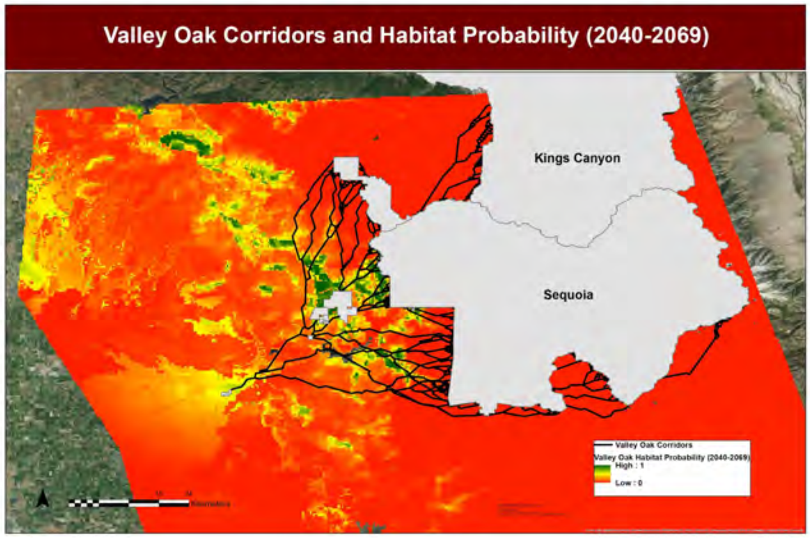
Valley Oak



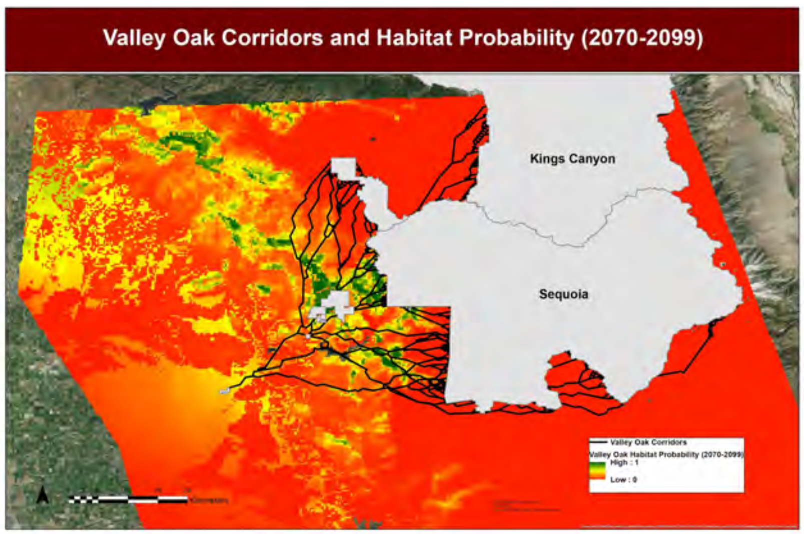
Appendix 30: Least cost paths overlaid on resistance for the valley oak



Appendix 31: Least cost paths overlaid on the MaxEnt output of current climate data for the valley oak



Appendix 32: Least cost paths overlaid on the MaxEnt output of 2040-2069 climate data for the valley oak



Appendix 33: Least cost paths overlaid on the MaxEnt output of 2070-2099 climate data for the valley oak

Appendix D: Contact Information

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