Cumulative Impacts of Large-scale Renewable Energy Development in the West Mojave

Effects on habitat quality, physical movement of species, and gene flow.

A Group Project submitted in partial satisfaction of the requirements for the degree of
Master of Environmental Science and Management at the
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As authors of this Group Project report, we are proud to archive it on the Bren School's website such that the results of our research are available for all to read. Our signatures on the document signify our joint responsibility to fulfill the archiving standards set by the Donald Bren School of Environmental Science and Management.

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The Group Project is required of all students in the Master of Environmental Science and Management (MESM) program. It is a four-quarter activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Final Group Project Report is authored by MESM students and has been reviewed and approved by:

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Abstract

To help slow our contribution to climate change, California's Governor has issued an executive order requiring an unprecedented one-third of statewide electricity production to come from renewable sources by 2020. California's West Mojave Desert contains ample renewable energy resources and undeveloped expanses; thus, many large-scale renewable projects have been proposed for the region. Such renewable energy development will have ecological consequences of its own, however, including fragmentation of sensitive ecosystems, and barriers to species movement and gene flow.

This project examines the cumulative impacts of large-scale renewable energy development, urban expansion, and climate change on two of the Mojave's flagship species: the bighorn sheep and desert tortoise. The results indicate that climate change impacts to species connectivity can be compounded by renewable energy developments, which decrease core and highly suitable habitat and can act as major obstacles to migration and gene flow. To help maintain connectivity within the West Mojave, renewable energy planners can reconsider developing projects within critical or highly suitable habitat, within connectivity pathways, and surrounding important source populations and climate refugia for the bighorn sheep metapopulation. Conservation organizations can prioritize existing landholdings important to connectivity, consider purchasing additional land or easements to protect connectivity, and support planning efforts by providing expertise to conduct additional connectivity analyses.

1.0 Executive Summary

Climate change is considered as one of the greatest environmental challenges of our time. To help combat climate change and its associated risks, the United States is looking toward renewable energy as a viable alternative to fossil fuel energy sources. To help slow our contribution to climate change, California's Governor has issued an executive order requiring one-third of statewide electricity production to come from renewable sources by 2020. In order to fulfill these unprecedented goals, developers are looking beyond distributed generation and small scale energy plants to large-scale wind and solar developments.

With its large, windy, open expanses, perpetually sunny days, and general lack of development, the West Mojave has quickly become the focus of in-state renewable energy planning. However, large-scale renewable energy development has ecological consequences of its own.

1.1. Project Significance

The purpose of this project is to examine the cumulative effects on habitat fragmentation, species movement and gene flow in the West Mojave, given specific scenarios of large-scale renewable energy development in the region. As we turn to large-scale solar and wind farms to satisfy our growing need for renewable energy, we must consider the impacts these projects can have to the immediate landscape as well as to ecological processes. The West Mojave contains some of the most pristine areas in California, and is home to more than 20 endangered or threatened species (CDFG 2009a) and several flagship species, including the desert tortoise (*Gopherus agassizii*) and the bighorn sheep (*Ovis Canadensis nelsoni*). Although individual project permitting and regional conservation planning efforts evaluate certain aspects of the environmental impacts of such projects, rarely do these avenues evaluate the cumulative impacts of a network of multiple projects.

1.2. Establishing Development Scenarios

This project calculated that California is expected to demand an additional 50,000 to 286,000 GWh of renewable energy in 2050. To meet these demands, providers have submitted numerous applications to the California Energy Commission and Bureau of Land Management (BLM) California Desert District to build solar and wind projects in the West Mojave region (BLM 2008). The applications range from 50 to 2,500 Megawatts each, and together would cover more than one million acres in the region (BLM 2009).

Because it is hard to predict exactly how many large-scale renewable energy developments will actually be built in the West Mojave, we began by creating two renewable energy development scenarios to bracket the minimum and maximum expected renewable energy demand in 2050. The California Energy Commission created the Renewable Energy Transmission Initiative (RETI) to determine where transmission lines to reach large-scale renewable energy developments must be built. RETI identified over 2,150 potential, proposed, or planned energy projects throughout the state of California and grouped them into Competitive Renewable Energy Zones (CREZs). Each CREZ can contain wind, solar, and geothermal projects, and there are 29 CREZs throughout the state of California. Eighteen zones exist either partially or wholly within the West Mojave study region. To satisfy the low predicted demand, the analysis assumed that six of the CREZs within the West Mojave – those which RETI identified as the most economically and environmentally viable – would be built. To satisfy the high predicted demand, the analysis assumed all eighteen zones within the study region would be developed.

In order to isolate the effects of renewable energy versus other development and change that will occur by 2050, all of the modeling done in this analysis was conducted on four scenarios.

- The **Present Scenario** reflects current vegetation types, present urban development, roads, and other infrastructure such as dams, aqueducts and canals.
- The **Future Baseline Scenario** reflects the features of the Present Scenario, but also incorporates additional urban development projected to 2050, and a simple climate change model of a 2°C temperature rise.
- The **Low Renewable Energy Development Scenario** (“Low Scenario”) reflects the Future Baseline Scenario with the addition of six CREZs in the western reaches of the study area.
- The **High Renewable Energy Development Scenario** (“High Scenario”) reflects the Future Baseline Scenario with the addition of all eighteen CREZs throughout the study area.

1.3. Connectivity Analysis

A connectivity analysis is useful to quantify how large-scale renewable energy development and associated infrastructure may cause barriers to species movement and gene flow. Generally, connectivity refers to the degree to which a landscape allows for the flow of organisms among habitat patches and populations, and it is imperative for both species survival and biodiversity. Individuals must be able to move between habitat patches to meet their resource needs, while populations must be connected to allow for dispersal, gene flow, and re-colonization (Bennet 2003); when populations are isolated, they become susceptible to inbreeding depression and are less able to adapt to varying environmental conditions like climate change (Frankham 2005).

This analysis employed a software program called Circuitscape to conduct a connectivity analysis for two flagship species of the Mojave Region: the desert tortoise and the desert bighorn sheep. Circuitscape uses circuit theory to predict connectivity by connecting populations to each other through the landscape, which acts as a circuit of varying conductance. The results highlight potential pathways that organisms might take to travel between populations and critical habitat areas given the conductance of the surrounding habitat.

1.3.1. Desert Tortoise Connectivity

The desert tortoise is found in the Mojave and is widely distributed in a variety of desert habitats, especially creosote scrub (USFWS 2008). Habitat fragmentation and barriers to movement can severely limit desert tortoise populations (Edwards *et al.* 2004). Although their historic habitat was relatively continuous in the West Mojave (Hagerty 2008), it is becoming more fragmented in the face of increased development and urbanization. Highways are specifically problematic due to the increased likelihood of fatal incidents with motor vehicles (Boarman *et al.* 1997). In fact, highways can depress desert tortoise population density as far as 400m away (Boarman and Sazaki 2006).

This analysis modeled connectivity pathways between eight desert tortoise critical habitats as designated by the 1994 Desert Tortoise Recovery Plan. The analysis indicates that there is a slight shift in desert tortoise movement patterns from the Present to Future Baseline Scenarios, likely due mostly to the modeled climate change. In the Low Scenario, the large-scale renewable energy development has relatively little impact on the connectivity of the desert tortoise; because the developments occur mainly to the west of the desert tortoise critical habitats, they do not significantly block tortoise movement. Interestingly, however, a number of project developments overlap with the western critical habitats. Although these developments may not affect tortoise connectivity to a large degree, they may compound habitat loss issues. Many of the CREZs in the High Renewable Energy Development Scenario are planned for areas important for tortoise connectivity and within desert tortoise critical habitats. Scattered CREZs surrounding critical habitats impeded tortoise movement to and from those habitats.

1.3.2. Desert Bighorn Sheep Connectivity

In the West Mojave, bighorn sheep exist in 69 small, distinct populations, each of which depends on migrants from other populations to maintain genetic diversity. Thus, bighorn sheep exist as a meta-population, and the individual populations and the habitat connecting them are highly important. Should one population become isolated or decline, every population is at a greater risk of extinction.

This analysis modeled connectivity between all 69 sheep populations, and conducted a more detailed analysis on a subset of eight populations. Bighorn sheep movement patterns between the Present and Future Baseline scenario for the eight populations are similar, although many pathways are constrained to higher elevations due to climate change. The connectivity analysis indicates that proposed future large-scale renewable energy development, especially in the High Scenario, obstructs major pathways for movement, such as the pathways between the southwest and northeast Mojave Desert.

Quantitative outputs from the Circuitscape connectivity model were combined with population genetic data to predict migration rates between bighorn sheep populations. Migration rates between all populations decrease from the Present to all three future scenarios. Specifically, migration rates between the San Gabriel Mountains population, the largest in the region, and populations in the northeast are significantly impacted. In the High Scenario, the migration rates between these populations decrease to near or below one migrant per generation, the minimum migration rate necessary to maintain adequate gene flow to prevent genetic isolation (Mills and Allendorf 1996). Cumulatively, large-scale renewable energy development could significantly impact gene flow between many other sheep populations as well, decreasing the viability of the entire metapopulation of desert bighorn sheep in the West Mojave.

1.4. Recommendations for Renewable Energy Development Planners

The team identified a number of federal and regional planning processes that can benefit from this type of analysis. Federal processes include the Western Regional Energy Zone initiative Phase 1 renewable energy zone identification process and Phase 2 transmission planning, as well as the BLM application streamlining process, which are all in early stages and can benefit from studies such as these, which can provide useful data and methods to evaluate connectivity concerns. The team also recommends that the BLM work with other land holding natural resource agencies to maintain connectivity between publicly owned areas of ecological significance.

State processes include the Renewable Energy Action Team planning process, which should work to specifically address connectivity and to include connectivity concerns in their Best Management Practices. The nearly complete Renewable Energy Transmission Initiative (RETI) Phase 2 transmission planning should address some of the connectivity concerns identified by these studies (where applicable, given the expedited timeframe). RETI could also consider re-analyzing the environmental impacts of specific problematic CREZs.

1.5. Recommendations for Conservation Organizations

Conservation organizations can help preserve connectivity in the West Mojave by actively participating in the planning processes above in order to provide expertise for analyses similar to this one, and perhaps recreate and expand upon our research. Possibilities include evaluating additional species and incorporating different development scenarios. Using some of the data provided by this report, conservation organizations can collaborate with agencies to identify and ensure the conservation and proper management of public holdings encompassing important connectivity areas, as well as identify private holdings that might be targeted for easements or acquisition to better ensure the conservation of connectivity in the West Mojave.

2.0 Objectives

The overarching objective of this project is to examine the cumulative impacts of large-scale renewable energy development on the connectivity of bighorn sheep and desert tortoises in California’s West Mojave. The objectives include:

1. Determine the location of urban development and likely renewable energy developments;
2. Create a model of connectivity for bighorn sheep and desert tortoise given climate change and development; and
3. Compare results from the present with future development scenarios.

The project ultimately provides recommendations to assist California’s renewable energy planners and conservation organizations develop renewable energy in a manner that minimizes ecological impacts.

3.0 Significance and Project Framework

Climate change is considered by many to be one of today's most significant environmental challenges. Scientists have estimated that over one million species are at risk of extinction by 2050 due to climate change (Thomas *et al*. 2004). Both national and state efforts to help combat climate change and its associated risks are focusing increasingly on the use of renewable energy as a viable alternative to the fossil fuels we currently rely on. For example, California passed energy legislation in 2002 establishing Renewable Portfolio Standards which require that 20% of all energy sold to retail customers come from renewable sources by 2010, and 33% by 2020 (Sher, Chapter 516, Statutes of 2002). Furthermore, in November 2008 Governor Schwarzenegger issued an executive order requiring one-third of state-wide electricity production to come from renewable sources by 2020 (Schwarzenegger 2008). With these increased renewable energy requirements, power providers can no longer fulfill quotas with small-scale renewable projects. As a result, many providers have begun exploring the feasibility of implementing large-scale renewable energy projects in the state.

The portion of the Mojave Desert that lies within California (the "West Mojave") is likely to become home to much of California's renewable energy development. Its valleys contain some of the best solar sites in the state, and the surrounding mountains confine wind to narrow passageways ideal for wind power. In fact, since 1996 the California Energy Commission and Bureau of Land Management California Desert District have received over 150 applications for solar and wind projects in the West Mojave. The applications range from 50 to 2,500 Megawatts each, and together would cover more than one million acres in the region (BLM-CDD 2009).

The West Mojave, however, contains some of the most pristine natural areas in California, and is home to more than 20 endangered or threatened species (CDFG 2009a), as well as several flagship species including the desert bighorn sheep (*Ovis canadensis nelsoni*), and the desert tortoise (*Gopherus agassizii*).

To survive, species such as these must be able to move between habitat patches to obtain resources such as food and water, and populations must remain connected to allow for proper gene flow. Thus, connectivity is a critical ecosystem process. In desert regions such as the West Mojave, the resources necessary to sustain life are both scarce and ephemeral, making any disruptions to connectivity particularly problematic.

As we turn to large-scale solar and wind development to satisfy our growing need for renewable energy, we must consider the impacts these projects could have to both the immediate landscape, as well as to ecological processes. Generally, the impacts of large-scale development projects can result in direct loss of species and habitats, habitat fragmentation, and disruptions to the physical movement of species and gene flow. Although individual project permitting and regional conservation planning requires the evaluation of certain environmental impacts associated with such projects, rarely do these avenues evaluate habitat fragmentation or connectivity in detail, nor do they address climate change or evaluate the cumulative impacts of the development of many projects over time.

Because the West Mojave is fast becoming the focus for renewable energy development in California, and because habitat fragmentation and disruptions to connectivity are of particular concern in desert ecosystems, the region is an ideal place to examine the effects of large-scale renewable energy development on these processes. This project examines the cumulative effects of specific large-scale renewable energy development scenarios on habitat quality, species movement and gene flow in the West Mojave.

In order to analyze these effects, the research group (1) identified how much new renewable energy capacity will be needed in California in 2050; (2) established scenarios for where this capacity might be built; (3) analyzed habitat quality in terms of fragmentation; (4) modeled connectivity across the West Mojave for two key species, the desert tortoise and desert bighorn sheep; and (5) examined impacts to physical movement and gene flow for these focal species. This analysis was then used to provide recommendations to California's renewable energy planners and conservation organizations concerning ways to develop renewable energy in a manner that preserves the ecological integrity of the region.

4.0 Study Region

The Mojave Desert spans approximately 48,000 square kilometers (about 31 million acres), reaching across California, Arizona, Nevada, and Utah (USGS 2006). The desert is bordered on the west by the Tehachapi, San Gabriel and San Bernardino mountain ranges, and is situated between the Sonoran Desert to the south and east and the Great Basin Desert to the North. Major metropolitan areas in the Mojave include Lancaster, Palmdale, Victorville, and Hesperia in California as well as Las Vegas in Nevada.

The study region used in this analysis was based on the Mojave Basin and Range Ecoregion designated by Omernik (1987) (See Figure 1). Ecoregions are designed to provide a spatial framework for environmental resource management and denote areas within which ecosystems and environmental resources are generally similar (USEPA 2003). Thus the use of this ecoregion as the basis for the analysis is appropriate.

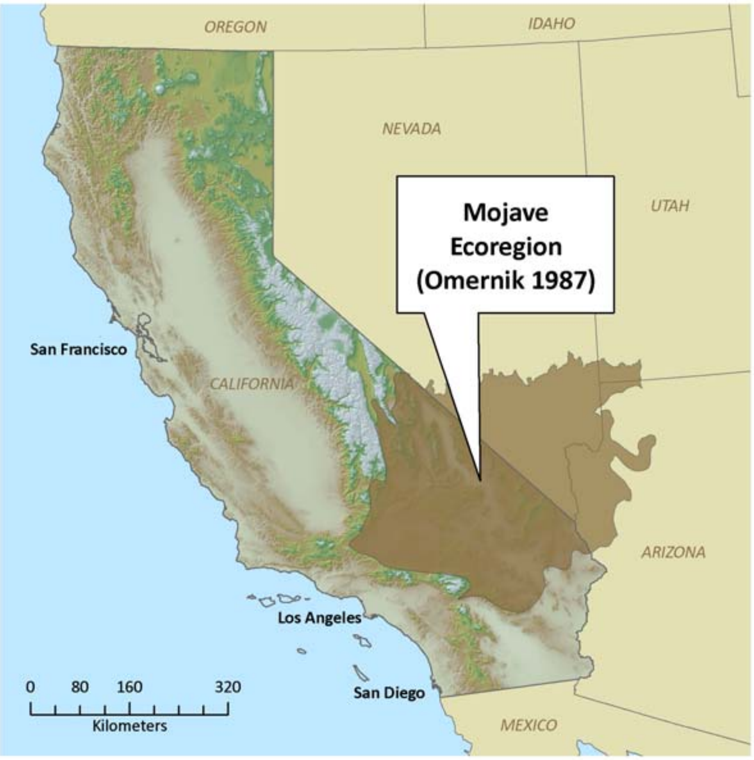


Figure 1. Omernik's Level III definition of the Mojave Basin and Range Ecoregion (Omernick 1987)

As opposed to analyzing the entire Mojave Basin and Range Ecoregion, a methodology similar to that employed by the Mojave Desert Ecosystem Program (Bailey 1995) was used to apply a 50 km buffer to the Mojave Basin and Range Ecoregion The buffer is intended to encompass areas that may belong to the ecoregion when defined by other systems of classification or that were excluded from the original polygon due to scale restrictions (Bailey 1995). Finally, the ecoregion and buffer were clipped to include only those parts within California (see Figure 2).

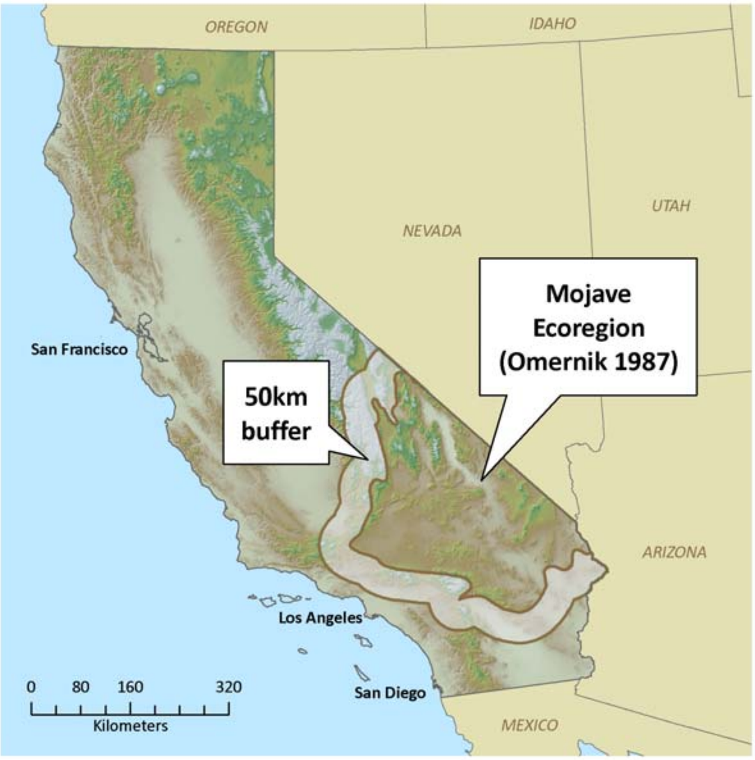


Figure 2. Construction of the West Mojave Study Region. The West Mojave study region includes the California portion of Omernik's Level III definition of the Mojave ecoregion combined with a 50km buffer to encompass all definitions of the ecoregion.

The resulting study region used for this analysis is shown in Figure 3 below.

Figure 3. The West Mojave study region.

At nearly 9.5 million acres, the West Mojave study region lies mostly to the northeast of the Los Angeles metropolitan area. The region includes approximately 2.7 million acres of military land, 300,000 acres of land administered by the National Park Service, 102,000 acres of land administered by the State of California, 3.2 million acres of land administered by the California Bureau of Land Management, and over 3.0 million acres of private land (BLM 2006).

4.1 Ecological Resources

The West Mojave is an ecologically significant region containing many diverse habitats, a multitude of endemic, rare, threatened, and or endangered species, and a variety of important protected areas and conservation efforts.

4.1.1 Habitats of the West Mojave

According to the California Department of Fish and Game's California Natural Diversity Database, the West Mojave encompasses nearly 30 habitat types, many of which are listed as "sensitive" (CDFG 2008). These sensitive habitat types include Joshua tree woodland, southern cottonwood-willow riparian forest, fresh-water marsh, alkali marsh, alluvial fan sage scrub, pinion-juniper woodland, and southern willow scrub.

4.1.2 Endemic, Rare, Threatened and Endangered Species

The West Mojave is home to a variety of endemic, rare, threatened, and endangered species. More than 200 endemic plants, 10 species of scorpions, 10 amphibians, 50 mammals, 48 reptiles, and 240 birds call the region home (CDFG 2009a; NAS 1979). The 24 federally and state-listed threatened and endangered species found in the West Mojave are listed in Table 1.

Table 1. Federally and State Listed
Threatened and Endangered Species of the Mojave Desert

Species	**Federal Listing**	**State Listing**
Amargosa Vole (*Microtus californicus scirpensis*)	E	E
Arizona Bell's Vireo (*Vireo bellii arizonae*)	-	E
Bald eagle (*Haliaeetus leucocephalus*)	-	E
Black Toad (*Bufo exsul*)	-	T
California Condor (*Gymnogyps californianus*)	E	E
California red-legged frog (*Rana aurora draytonii*)	T	-
Cottonball Marsh Pupfish (*Cyprinodon salinus milleri*)	-	T
Cushenbury milkvetch (*Astragalus albens*)	E	-
Cushenbury buckwheat (*Eriogonum ovalifolium var.*	E	-
Cushenbury oxytheca (*Oxytheca parishii var.*	E	-
Desert tortoise (*Gopherus agassizii*)	T	T
Inyo California towhee (*Pipilo crissalis eremophilus*)	T	E
Lane Mountain milkvetch (*Astragalus jaegerianus*)	E	-
Least Bell's vireo (*Vireo bellii pusillus*)	E	E
Mohave ground squirrel (*Spermophilus mohavensis*)	-	T
Mohave Tui Chub (*Gila bicolor mohavensis*)	E	E
Mojave tarplant (*Hemizonia Deinandra] mohavensis*)	-	E
Parish's daisy (*Erigeron parishii*)	T	-
Southern Rubber Boa (*Charina umbratica*)	-	T
SouthWest willow flycatcher (*Empidonax traillii*	E	-
Swainson's hawk (*Buteo swainsoni*)	-	T
West yellow-billed cuckoo (*Coccyzus americanus*	-	E
Willow Flycatcher (*Empidonax traillii*)	-	E
Yuma Clapper Rail (*Rallus longirostris yumanensis*)	E	T

E
= Endangered; T = Threatened *Source: CDFG 2009a*

4.1.3 Important Environmental Areas and Conservation Efforts

The West Mojave study region includes large portions of Joshua Tree National Park as well as four other state parks and wildlife areas, and numerous ecological reserves, mitigation lands and conservation easements managed by the California Department of Fish and Game. Many county and regional parks are also located in the West Mojave, including five Inyo County Environmental Resource Areas, three Los Angeles County Significant Ecological Areas, and various wildlife and wildflower sanctuaries. Local municipalities have also designated numerous parks and protected areas in the region (BLM-CDD 2005).

In 1976, Congress designated 25 million acres of Southern California as the California Desert Conservation Area (CDCA), most of which is encompassed by the West Mojave Study area. CDCA management strategies simultaneously allow for multiple uses, sustained yield, and environmental protection. The Bureau of Land Management (BLM) manages nearly half of the CDCA; the remaining areas are managed by other government agencies, including the National Park Service, Fish and Wildlife Service, and the National Forest Service. The CDCA includes 85 areas identified by the California Bureau of Land Management as “areas of critical environmental concern,” 69 areas designated by Congress as “wilderness areas,” and 22 wilderness study areas (BLM 2006).

The Bureau of Land Management has made additional efforts to protect sensitive areas in the Mojave Desert. In 2002, the BLM amended the CDCA management plan and designated 1.5 million acres as Desert Wilderness Management Areas (DWMAs) to provide habitat for the federally threatened desert tortoise and other species of concern. Although mining and off road vehicles are allowed in DWMAs, management policy indicates that no more than 1% of these critical areas should be disturbed (BLM 2009).

In 2006 the BLM developed the West Mojave Plan (BLM-CDD 2005) as a regional strategy for conserving and protecting species and habitats of concern in the West Mojave in the context of a habitat conservation plan and a federal land use plan. Although the document is contentious, its policies aim to help protect endangered species and sensitive habitat.

The most recent conservation effort to be undertaken in the region is the Desert Energy Conservation Plan. Under Governor Schwarzenegger’s 2008 Executive Order pertaining to renewable energy, the state created the Renewable Energy Action Team (REAT) to streamline renewable energy projects in the desert. The team is made up of the California Department of Fish and Game, the California Energy Commission, the United States Department of the Interior, the United States Bureau of Land Management, and the United States Fish and Wildlife Service. In response to the rising number of applications for renewable energy development in the Mojave Desert, REAT is tasked with formulating the Desert Energy Conservation Plan to effectively protect natural resources within the Mojave, while allowing responsible renewable energy development (Office of the Governor 2008).

4.2 Landscape Value

With many areas still largely undeveloped, the West Mojave Desert may present one of the best opportunities to conserve areas significant to many ecological processes in the region, including connectivity for species movement between the lower Sonoran desert to the south and the upper Great Basin Desert to the north, as well as between areas to the west, such as the Tehachapi Mountains and the Los Padres and Angeles National Forests. Such connectivity will become ever more critical as climate change threatens to force species out of established reserves (Araujo *et al*. 2004). However, undeveloped land in California is a scarce resource and many competing development pressures exist in the region including those posed by expanding urban areas and large-scale commercial and military installations.

4.3 Recreation Value

The West Mojave study area includes both Death Valley and Joshua Tree National Parks, which collectively generate over two million recreational visitors each year (NPS 2008a, 2008b). The study area also encompasses the 1.6 million acre Mojave National Preserve, which is home to Big Morongo Canyon Preserve, Rainbow Basin, Owl Canyon, and the Kelso Dunes.

Recreational opportunities within these areas include hiking, backpacking, camping, horseback riding, wildflower viewing, birdwatching, and hunting. The area is home to several historic sites including abandoned mines, homesteads, and military outposts. The Mojave also hosts off-road vehicle opportunities, including Stoddard Valley, Johnson Valley, and the Dumont Dune. Collectively, the recreational areas of the Mojave provide a haven of recreational activities for visitors from the surrounding metropolises of Los Angeles, Orange County, and Las Vegas.

5.0 Conserving Habitat Quality and Connectivity

Large-scale development of any kind can result in ecological impacts such as species and habitat loss, fragmentation, and disruptions to movement of species and to gene flow. Such impacts are likely to be exacerbated by the shifting of habitats and species with climate change. Although individual project permitting and regional conservation planning efforts do evaluate certain environmental impacts associated with large-scale renewable energy development, rarely do these avenues evaluate habitat fragmentation or connectivity in detail. They also do not attempt to evaluate the potential cumulative impacts posed by many projects over time, or the impacts those projects might have in the face of climate change. Thus, there is a critical and unmet need to identify and analyze the potential effects of large-scale renewable energy development and climate change on habitat quality, species movement, and gene flow in the West Mojave.

5.1 Habitat Fragmentation

Habitat fragmentation can also harm species by decreasing connectivity and biodiversity while increasing habitat loss (Weng 2007, Southerland 2004, Wilcove *et al*. 1998, Theobald *et al*. 1997). The effects of fragmentation are amplified by the fact that they are not confined solely to the area that is physically developed. A small amount of development may alter an entire landscape through the creation of microclimates, isolation of habitat patches, alteration of biogeochemical cycles, and the disruption of spatial processes such as migration (Forman and Alexander 1998). These changes are especially harmful to species that have adapted to specific climates, habitats, or physical characteristics of a particular landscape (Saunders *et al*. 1991).

5.2 Connectivity

Generally, connectivity refers to the degree to which a landscape allows for the flow of organisms among habitat patches and populations, and it is imperative for both species survival and biodiversity (Bennett 2003). Individuals must be able to move between habitat patches to meet resource needs, while populations must be connected to allow for dispersal, gene flow, and re-colonization. If populations are isolated they become susceptible to inbreeding depression and are less able to adapt to varying environmental conditions like climate change. In desert regions such as the West Mojave, resources to support life are particularly scarce and ephemeral; thus, disruptions to species movement or gene flow are particularly problematic. However, because connectivity is difficult to define and measure, impacts to connectivity are often overlooked during planning.

The manner in which a landscape facilitates or impedes movement will have a major impact on the survival of a species. Resources necessary for survival are distributed in patches across a landscape, and individuals must move among these patches to acquire a full complement of resources or to supplement existing resources (Taylor et al. 1993). An individual's ability to obtain resources from any given patch depends on the ease with which it can reach the patch, which in turn is determined by the distance between patches, the biophysical nature of the route, and the biology and behavior of the organism (Taylor et al. 1993). Highly mobile species such as birds or large mammals are able to move many kilometers per day and can overcome obstacles to movement. Other less mobile species such as reptiles, however, must find all their necessary resources within shorter distances and are thus more easily confined (Taylor et al. 1993).

Because the ability to move through a landscape is critical to species survival, understanding movement patterns is essential to conservation planning and ecosystem management. Wildlife managers often monitor animals that move on a regular basis (seasonally or daily) between habitats to meet resource needs, and observations of the negative impacts of local barriers to movement on species survival are extensive (Bennett 2003).

Gene flow refers to the transfer of genetic variants between populations of a species. Gene flow is essential to maintaining genetic diversity, and is highly dependent on species movement (Coulon *et al*. 2004). The International Union for Conservation of Nature (IUCN) considers genetic diversity a level of biodiversity that requires conservation (McNeely *et al*. 1990). Despite its crucial nature, gene flow is an often-overlooked aspect of conservation goals. Human land-use causes habitat loss and fragmentation and inherently results in smaller native plant and animal populations of varying isolation. Inbreeding depression, loss of genetic diversity, and mutation accumulation are all genetic factors present in small isolated populations that can increase extinction risk (Frankham 2005). These factors have varying effects, with inbreeding depression causing the most drastic short-term reductions in genetic fitness due to increased homozygosity (decreased genetic diversity) (Amos & Balmford 2001). Loss of genetic variability and mutation accumulations tend to have more long-term, less drastic, and more variable effects on genetic fitness, yet there is strong evidence that these factors also contribute to extinction risk (Amos & Balmford 2001).

Periodic out-breeding via migration or dispersal can minimize or eliminate the effect of genetic factors on extinction risk, with one migrant per generation considered the desired minimum migration rate (Mills & Allendorf 1996). Gene flow within a population is highly influenced by habitat connectivity and species movement (Coulon *et al*. 2004); species dispersal, migration, and reproductive traits are thus important factors in assessing habitat connectivity that will provide for adequate gene flow between or among populations.

Ecological theory highlights the benefits of connectivity (both in terms of species movement and gene flow) to wildlife conservation. For example, island biogeography theory predicts that movement of individuals between fragmented habitats will (1) enhance the conservation status of a species by maintaining a higher level of richness at equilibrium; and (2) increase colonization to supplement declining populations (Bennett 2003). Moreover, due to increasing landscape fragmentation, metapopulation theory (where individuals disperse between separate local populations in suitable habitat patches, essentially forming a single, larger regional population) has become the prevalent conceptualization of wildlife population structure. The ability of individuals to move through the landscape is crucial to the way a metapopulation functions. Populations that retain high connectivity with other populations are recolonized rapidly and are less likely to succumb to extinction, thereby increasing the stability of the larger regional population (Bennett 2003). Finally, landscape ecology theory recognizes both natural and developed environments as mosaics; thus, a species' ability to live within and move through these mosaics is essential (Bennett 2003).

As habitat fragmentation increases the number of and effective distance between resource patches, habitat corridors- or linkages between resource patches- have come to the forefront as a means of preserving species movement. Corridors are natural areas that connect two habitats of ecological value, facilitating species movement between the habitats and thus reducing the effects of fragmentation.

In order for these corridors to be effective, they must allow for ecological processes such as:

- Travel and migration of wide-ranging mammals;
- Propagation of plants;
- Genetic interchange;
- Movement of populations as a response to environmental changes and natural disasters
- Re-colonization of habitats from which populations have been locally extirpated (Beier & Loe 1992).

Wildlife corridors that allow for such processes will be the most likely to meet the needs of the species they are meant to protect. A single corridor may be used by multiple species, but must be designed with the single species it is meant to protect in mind if it is to adequately meet the needs of that species. Complex ecological relationships prohibit planners from generalizing wildlife corridor dimensions, including length, topography, and vegetation. However, wildlife corridors created for large mammals may also benefit many other species, such as the species that depend on those large mammals as dispersal agents (Soule & Terborgh 1999).

Although there is no wealth of studies proving the necessity of habitat corridors, observational evidence and theory upholds the importance of connectivity (Bier & Noss 1998). Studies suggest that corridors can be valuable conservation tools (Bier & Noss 1998); Species persistence requires connectivity between populations, and preserving the habitat corridors between populations can also provide umbrella protection for other species.

5.3 Climate Change

Changes to habitat quality and connectivity from urban and other large-scale development will likely be exacerbated by climate change. Thus, understanding the relationship between climate change, habitat fragmentation, and connectivity is important to planning, as it can help planners identify connectivity areas that are necessary for long-term species survival and preservation.

Climate change will likely compound habitat fragmentation since changes to temperature and precipitation will transform existing habitats, decrease habitat quality, and/or reduce the number of available habitat patches for specific species. In areas where habitat becomes more scarce or dispersed due to climate change, connectivity will likely play an even greater role in population viability.

As vegetation distributions and habitats change due to the changing climate, species movement and migration rates will also change. Species will need to disperse to new areas if previously preferred habitats become inhospitable due to changes in precipitation and temperature (Hulme 2005). Species living in fragmented habitats may be particularly vulnerable to climate change if dispersal to new sites is limited (Walther *et al*. 2002 as cited in Epps 2004), since gene flow will be altered as migration and dispersal behavior reacts to changing environmental conditions.

5.4 Importance of Habitat Fragmentation and Connectivity for Study Species

To best illustrate the effects on habitat quality and impacts to connectivity that might arise from large-scale renewable energy development and climate change in the West Mojave, two key species were analyzed: the desert bighorn sheep and the desert tortoise.

The desert tortoise and bighorn sheep were chosen because they require large-scale connectivity for survival (Epps *et al.* 2005; Edwards *et al.* 2004), and therefore epitomize the need to maintain connectivity in the study area. Both species are well-studied iconic species of the West Mojave, and information and data about the two is widely available. Finally, both species are of national concern; the desert tortoise is listed as federally threatened, and bighorn sheep populations outside the Mojave are listed as federally endangered, making conservation of these species particularly important.

5.4.1 Desert Bighorn Sheep

Desert bighorn sheep (*Ovis Canadensis nelsoni*) are one of the few large mammals that live in the Mojave Desert, and are considered by the California Department of Fish and Game as a flagship species for the region (CDFG 2009b). Although they cannot coexist with humans (Cain *et al*. 2007), they are valuable to society both aesthetically and economically. Tourists are willing to spend a significant amount of money on recreation involving wildlife viewing and hunting of bighorn sheep (Cain *et al.* 2007), and pay up to $500 for sheep hunting permits (CDFG 2009c). For the 2008-2009 hunting season, hunters submitted over 6,000 applications for permit tags, though only 23 permits were granted (CDFG 2009c).

Approximately 3,100 to 5,700 individual bighorn sheep exist in the wild (Epps *et al*. 2003). They are found in mountainous areas with rocky barrens, meadows, and brushlands (CDFG 2009c). They are adept climbers, and are often found in areas with slopes of 10% or greater, which provide them with escape routes from perceived danger (Epps *et al*. 2007).

Bighorn sheep are generally limited to their steep, mountainous habitat, and exist as a metapopulation made up of smaller, separated populations. The Mojave Desert study region employed in this analysis is home to 69 discrete populations (CDFG 2005) whose sizes currently range from less than 25 to over 300 individuals (Epps *et al*. 2003), though many populations have less than 50 individuals (Epps *et al*. 2007) (see Figure 4). Individuals from within these discrete populations are known to move large distances to re-colonize new territory and find mates in other populations. Such movement serves to maintain genetic viability across the populations (Epps *et al*. 2005). Since migrant individuals from Mojave populations can refresh the gene pool of other populations, the extinction of any of these local populations will affect the species as a whole. Thus, habitat fragmentation and disruption of species movement and gene flow is of specific concern for this species.

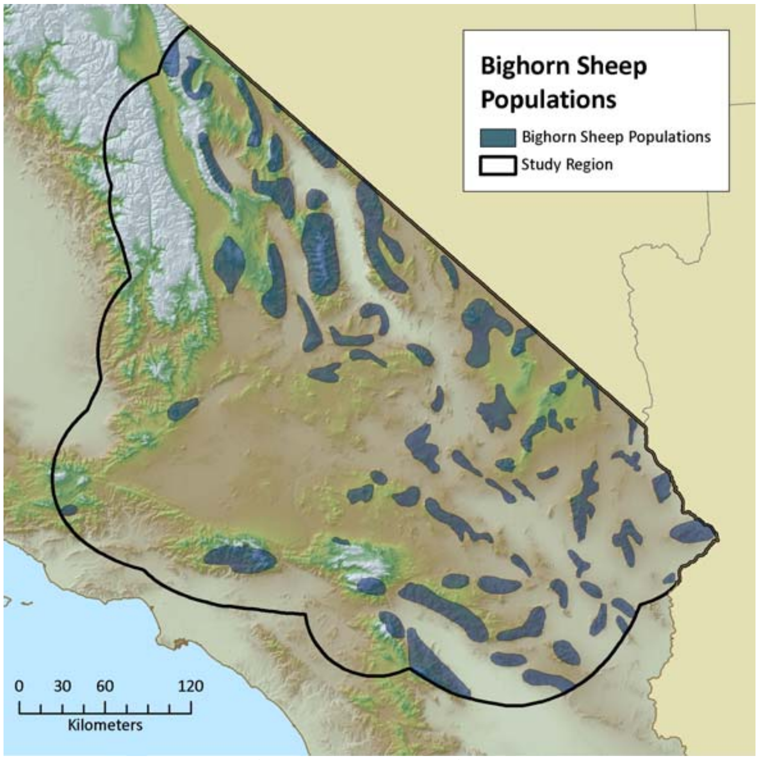


Figure 4. Desert Bighorn Sheep Populations of the West Mojave. The West Mojave study region employed in this analysis is home to 69 discrete populations of desert bighorn sheep ranging from less than 25 to over 300 individuals.

Bighorn sheep tend to avoid humans. Outdoor recreation in their habitat, such as hiking, biking and use of off-road vehicles has been linked to the decline of some bighorn sheep populations (Papouchis *et al*. 2001). In addition to impacts from direct interaction with humans, development has been shown to negatively affect the species as well. Development includes barriers to sheep movement such as infrastructure, highways, water canals, and fenced areas (Epps *et al*. 2005) which can interrupt dispersal and hasten the decline of the species (Bleich *et al*. 1990, Krausman *et al*. 2000). For example, although sheep will often cross two-lane roads, they tend to avoid four-lane highways, which have been shown to increase mortality from accidents with vehicles (Epps 2005a). Similarly, such barriers reduce the probability that any species will re-colonize a land parcel once previous populations are eliminated (Theobald *et al*. 1997). This is the case with sheep, which are slow to re-colonize territory where previous sheep populations were unable to persist (Bleich *et al*. 1990). Furthermore, barriers to movement obstruct migration pathways between discrete sheep populations. This is a major concern because populations must generally receive at least one migrant per generation to maintain genetic diversity and prevent inbreeding (Wang 2004). The Sierra Nevada and Peninsular Mountain populations are federally endangered (USFWS 2009) and the individual population viability of West Mojave bighorn sheep populations is already unstable, as at least 26 desert populations have gone extinct in the latter half of the 20th century. (Epps *et al*. 2003, Epps *et al*. 2005b). Development further threatens this viability by imposing additional barriers to movement.

In order to insulate bighorn sheep from increased habitat fragmentation and impacts to species movement and gene flow associated with development, primary sheep habitat and the areas between habitats (the intermountain areas) require protection (Bleich *et al*. 1990). These areas are necessary to sheep for travel and lambing, and facilitate interaction between neighboring populations. While protecting movement between populations helps maintain genetic diversity, which is essential for meta-population viability (Bleich *et al*. 1990), scientists have already observed genetic isolation among populations due to the present urban and highway development (Epps *et al*. 2005a). Sheep populations isolated by such human development experienced a 15% reduction in genetic diversity in as little as 40 years (Epps *et al*. 2005a). Desert bighorn sheep populations at lower elevations also have lower genetic diversity due to population fluctuations and bottleneck effects as a result of climatic fluctuations in the latter half of the 20th century (Epps *et al*. 2006).

Future climate fluctuations due to climate change will likely impact bighorn sheep as well. In order to maintain evolutionary potential as the climate and vegetation communities continue to change, gene flow between low elevation populations and high elevation populations, which serve as genetic diversity reservoirs, will be necessary (Epps *et al.* 2006).

5.4.2 Desert Tortoise

Like the bighorn sheep, the desert tortoise (*Gopherus agassizii*) is considered a flagship species in the West Mojave region, with intense public interest in its preservation and persistence. Since 1990, the desert tortoise has been listed as “threatened” by the federal government and is therefore protected under the Endangered Species Act. A recovery plan was published in 1994 designating critical habitat areas for the species and creating a conservation management framework (see Figure 5). A new draft of the recovery plan is currently under review (USFWS 2008).

The desert tortoise is found in the Mojave, Sonoran, and Colorado deserts of the Southwest (Marlow 2000). Widely distributed in a variety of desert habitats including predominantly creosote scrub (USFWS 2008), desert tortoises are long-lived and have home ranges of approximately 2-5 hectares (5-38 acres) in the West Mojave (Marlow 2000). Their diet consists mainly of grasses, especially spring annuals (Marlow 2000).

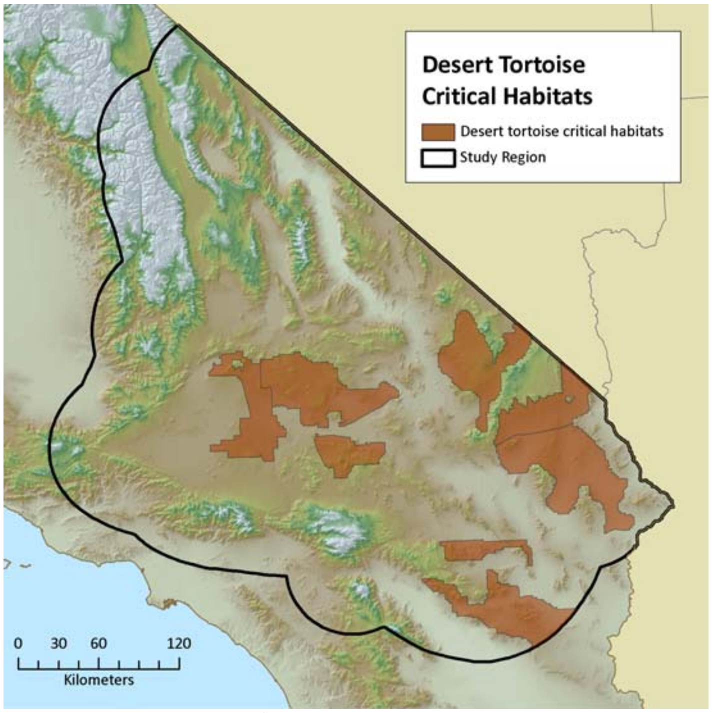


Figure 5. Desert Tortoise Critical Habitats in the West Mojave. The West Mojave study area employed in this analysis encompasses eight desert tortoise critical habitat areas as designated by the 1994 Desert Tortoise Recovery Plan (USFWS 2008).

Tortoises are sensitive to extreme temperatures; their ideal body temperature is between 80−90ºF. Because their body temperature fluctuates with the surrounding ground and air temperatures, tortoises must burrow to adapt to the desert's extreme temperatures (Davidson 2002; Garrison 2008). Because temperatures can reach well over 100 ºF in the desert, direct exposure can kill a tortoise in an hour or less (Marlow 1979 as cited in Marlow 2000). Thus, tortoises must remain in their burrows except to forage in early morning and late evening (Garrison 2008). In addition, the desert tortoise exhibits temperature-dependent sex determination of hatchlings (Baxter 2008). Fluctuations in the temperature regime due to climate change could therefore affect sex ratios and have consequences on gene flow (Ken Nussear & Todd Esque, personal communication, November 2008 – January 2009).

Habitat fragmentation and barriers to movement can severely limit desert tortoise populations (Edwards 2004). Although their historic habitat was relatively continuous in the West Mojave (Hagerty 2008), it is becoming more fragmented in the face of increased regional development. Because tortoise home ranges tend to extend within 40 hectares, high quality habitat among and between populations must be maintained (Marlow 2000). Otherwise, degradation and loss of prime habitat will impede species movement and gene flow, resulting in increased extinction risk (USFWS 2008).

Desert tortoises can tolerate some development, but infrastructure can limit their movement. They are often unable to cross culverts (Boarman *et al*. 1997), highways, or canals (Edwards 2004). Highways are specifically problematic due to the increased likelihood of fatal incidents with motor vehicles (Boarman *et al*. 1997). In fact, roads can effectively depress desert tortoise populations located as far as 400 meters from the paved roads (Boarman & Sazaki 2007).

Because desert tortoises are long lived and their sexual maturity is delayed, they are not able to adapt easily to habitat loss or fragmentation (Edwards 2004). Habitat fragmentation can also isolate desert tortoise populations, thereby reducing their chance of survival by amplifying the chances of inbreeding depression and limiting their ability to respond to catastrophes (Boarman *et al*. 1997). These effects can be mitigated if tortoises can move from one population to another improving genetic variability (Edwards 2004). Therefore, protecting suitable habitat between populations is critical to maintaining species viability.

Biologists are researching new ways to help desert tortoises respond to habitat fragmentation and barriers to movement. For instance, installation of barrier fences may allow safe crossing of culverts, and translocation may provide another option for conserving the species (Boarman *et al*. 1997). Although these methods may help mitigate the negative effects of fragmentation, intentionally avoiding fragmentation and connectivity barriers is preferable.

Researchers at USGS are also currently working to model the desert tortoise's future range in the face of climate change (Ken Nussear & Todd Esque, personal communication, November 2008 – January 2009). If the range of this temperature-sensitive species does indeed change, the effects of habitat fragmentation and barriers to species movement may be exacerbated. Thus, with the combined threats of human development and climate change, the role of connectivity is even more important for the survival of this species.

6.0 Renewable Energy in the West Mojave

In the last ten years, California's population has expanded by nearly half a million residents yearly, and will likely continue to grow at similar rates for many years to come (State of California 2007) (see Figure 6). Settlements such as Palmdale, Lancaster, Victorville, Ridgecrest, and Barstow have grown rapidly around transportation corridors leading from the Los Angeles metro area, as well as around current military bases. These settlements are likely to continue to grow and impact the regional environment as the city of Los Angeles continues to grow, and as military operations focus on desert warfare scenarios since the attacks of September 11, 2001 (Sleeter & Raumann 2005). In fact, population growth in Inyo, Kern, Los Angeles, and San Bernardino counties is expected to exceed 38%, 216%, 36%, and 113% respectively over the next 40 years (State of California 2007). The demand for energy throughout California will likely also increase dramatically as population grows and development continues.

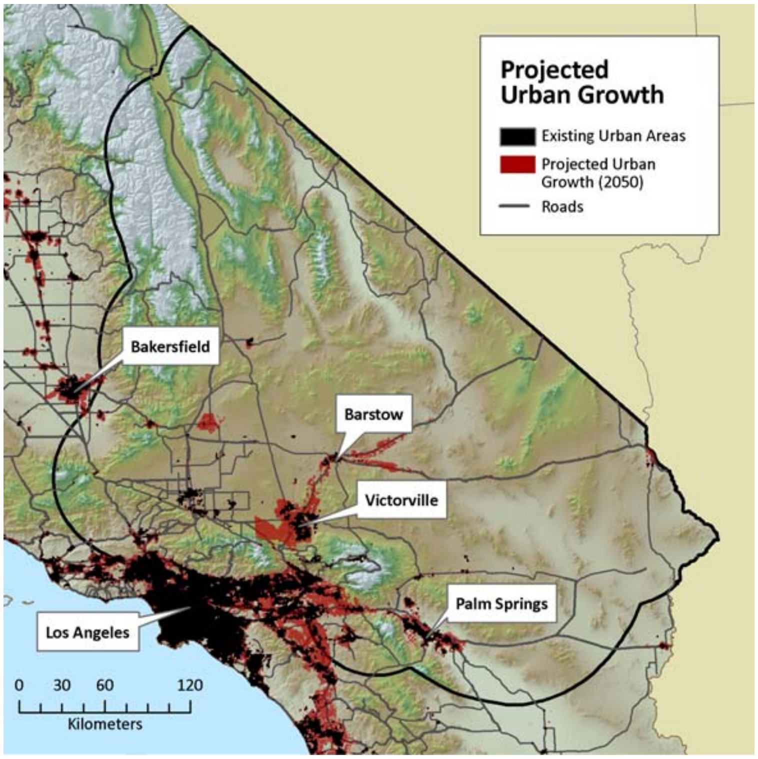


Figure 6. Existing and projected urban growth in the West Mojave.

6.1 Need for Renewable Energy

Climate change is considered by many to be one of the greatest environmental challenges of our generation. Scientists have estimated that over one million species are at risk of extinction by 2050 due to climate change (Thomas *et al*. 2004), caused at least in part by the ways in which we obtain our energy. To help combat climate change and its associated risks, the United States is looking increasingly toward renewable energy as a viable alternative to the fossil fuels we currently rely on. Under President Barrack Obama's "New Energy for America" plan, the federal government will invest over $150 billion in clean energy over the next ten years with the goal of supplying 25% of the nation's electricity through renewables by 2025 (The White House 2009).

In an effort to increase the diversity and reliability of the state's energy resources, as well as to address environmental concerns such as climate change, California passed energy legislation in 2002 establishing Renewable Portfolio Standards. The Standards require that 20% of all energy sold to retail customers in California come from renewable sources by 2010, and 33% by 2020 (Senate Bill 1078 2002). Furthermore, in November 2008, Governor Schwarzenegger issued an executive order requiring one-third of statewide electricity production to come from renewable sources by 2020 (Schwarzenegger 2008).

With these increased renewable energy requirements, power providers can no longer fulfill their quotas with small-scale renewable projects. As a result, many providers have begun exploring the feasibility of implementing in-state large-scale renewable energy projects.

6.2 Understanding the Impacts of Large-scale Renewable Energy Development

With large, windy, open expanses, perpetually sunny days, and general lack of development, the West Mojave holds much promise for the large-scale renewable projects the state will need to fulfill its renewable energy goals.

A number of large-scale renewable energy plants have already been constructed within the West Mojave, including the former Solar One and Solar Two demonstration solar power towers, as well as large wind farms at San Gorgonio Pass and Tehachapi Pass. Other development is already approved, such as the Mojave Solar Park, which is projected to be the world's largest solar thermal power facility in both size (nine square miles) and megawatts (553). Since 1996 the California Energy Commission and Bureau of Land Management California Desert District have received over 150 applications for solar and wind projects in the West Mojave region (BLM 2009). The applications range from 50 to 2,500

Megawatts each, and together would cover more than one million acres of the region (BLM-CDD 2009).

While renewable energy production has a much smaller carbon footprint than many other conventional methods of energy production, large-scale renewable energy development can pose other environmental consequences. The impact of large-scale renewable energy projects varies with the technology used. The generation of electricity using solar energy technology, including photo voltaic and solar thermal technology, can pollute soil and groundwater, release toxic chemicals, disrupt viewscapes, produce greenhouse gas emissions, and disturb ecosystems (Tsoutsos *et al*. 2005). On the other hand, wind projects may increase erosion in desert areas, alter vistas, disturb wildlife habitat, generate unwelcome noise, and be a hazard to birds and bats (Kuvlesky *et al*. 2007). Furthermore, transmission lines required for energy projects will increase the number of birds electrocuted each year by collisions with power lines (Kuvlesky *et al*. 2007).

Other general impacts associated with large-scale renewable energy development include:

- Habitat loss at project sites, and from associated infrastructure such as roads, buildings and transmission lines (Kuvlesky *et al.* 2007);
- Habitat degradation due to grading for sites, roads, and construction activities (Kuvlesky *et al.* 2007);
- Decrease in biodiversity associated with the presence of roads (Trombulak & Frissell 2000);
- Decreased mobility of species (especially small mammals and large ungulates) associated with roads (Conrey & Mills 2001); and
- Increased risk of invasive species due to new roads (Kuvlesky *et al*. 2007).

While attempts are made to mitigate the environmental impacts of individual projects, the cumulative impacts caused by the development of a network of projects are often not adequately addressed. In order to fully understand these cumulative environmental impacts, land managers must analyze development on a landscape scale. Thus, the focus of this study is the cumulative impacts of multiple large-scale renewable energy developments on habitat quality, species movement, and gene flow.

Impacts of large-scale renewable energy development on desert bighorn sheep and desert tortoise are of significant concern because they are flagship species in the Mojave. For more information on the needs of these species and their individual response to development, see Sections 5.4.1 – 5.4.2.

6.2.1 Effects on Habitat Quality

Large-scale renewable energy projects can exacerbate habitat loss and fragmentation, primarily through the construction and operation of infrastructure such as facilities, transmission lines, and associated roads. The development of large-scale renewable energy projects is likely to:

- Increase vehicle-wildlife collisions with snakes, lizards, small mammals, and birds, many of which may be endangered (Kuvlesky *et al.* 2007)
- Alter the composition of native communities due to increased non-native species along roadsides (Sears & Anderson 1991).
- Alter biodiversity and spatial patterns through fences, roads, and newly-disturbed areas, causing species to change their normal movement patterns (Theobald *et al.* 1997, Kuvlesky *et al.* 2007).
- Isolate species (Theobald *et al.* 1997), causing them to become susceptible to demographic, environmental and genetic stochasticity and amplifying extinction rates (Bruinderink *et al*. 2003).
- Increase animal-human interactions and their associated impacts. For example, human presence may alert animals to flee danger. Some animals may flee as far as 300m, wasting important metabolic energy (Gabrielson & Smith 1995).
- Decrease the recreation value of nature tourism and hunting (Kuvlesky *et al.* 2007)

6.2.2 Effects on Connectivity

Since many large-scale renewable energy developments proposed for the US and the Mojave Desert are still in the planning phases, there has been little study of the effects of these types of development on connectivity. As with other development, however, unwisely planned or dispersed sighting of large-scale renewable energy development and its associated infrastructure may cause barriers to species movement and gene flow.

In order to mitigate such consequences, planners must incorporate spatial planning regarding connectivity early in the development process. If connectivity is valued as an ecological service and given weight in planning decisions, then many consequences associated with fragmentation as well as barriers to species movement and gene flow could be avoided.

6.2.3 Efforts to Assess Impacts of Energy Development in the Region

Government agencies, developers, environmental non-profit organizations, and private citizens are all affected by how large-scale renewable energy projects will unfold in the West Mojave region. Although individual project permitting and regional conservation planning requires the evaluation of certain environmental impacts associated with such projects, rarely do these avenues evaluate habitat fragmentation, species movement or gene flow in detail, nor do they address climate change or evaluate the cumulative impacts of the development of many projects over time.

6.2.3.1 Project Permitting and Environmental Documentation

The development process requires completion of an Environmental Impact Report for each individual project. This documentation provides an analysis of the direct and cumulative environmental impacts of the project on the proposed location. While most projects can adequately address impacts on the composition of ecosystems (e.g. by avoiding sensitive areas or mitigating for impacts to species of concern), environmental analyses rarely take into account the cumulative effects of the proposed project in conjunction with existing or other proposed projects, or do so in only a cursory way. Unfortunately, this limited view in planning and permitting processes also means the evaluation of larger-scale impacts such as habitat fragmentation, barriers to species movement, and barriers to gene flow, is scarce.

6.2.3.2 Regional Renewable Energy Planning Efforts

The *Western Renewable Energy Zones (WREZ) initiative* was launched in 2008 as a joint program between the Western Governors' Association and the U.S. Department of Energy. Spanning 11 states, two Canadian provinces, and parts of Mexico, the WREZ initiative is one of the largest-scale renewable energy planning efforts. The initiative aims to identify Renewable Energy Zones (REZs) and necessary transmission lines throughout the western United States. Phase 1 (identifying REZs) will be completed in June 2009. Phase 2 (identifying transmission lines) will be completed by Fall 2009.

The Bureau of Land Management (BLM), anticipating an increase in demand of BLM lands on which to site renewable energy projects, is formulating a number of *renewable energy Programmatic Environmental Impact Statements (PEIS)* in conjunction with various other federal agencies. These documents establish agency-wide policy, outline best management practices, identify possible mitigation measures, and (where applicable) address land use amendments needed to streamline renewable energy development on BLM lands in the western United States, while simultaneously addressing possible environmental concerns related to this development (BLM 2005; BLM & USFS 2008a and 2008b; USDOE & BLM 2008).

- *Wind PEIS.* The Wind PEIS was finalized in 2005, and considers the impacts of wind development in terms of region-wide processes such as soil erosion and habitat fragmentation from roads, turbines, and other structures. However, the document does not specifically analyze connectivity; the ecological impacts discussed are generally direct impacts, such as species mortality and habitat loss due to facility construction and operation. The ecological discussion includes habitat reduction, alteration, fragmentation, and potential alterations to animal behavior (such as a change in migratory pathways) as a result of facility construction and operation (BLM 2005). The PEIS attributed the majority of animal behavioral change to the construction process and thus determined that these effects mainly occur in the short term. Importantly, the PEIS discusses a study of pronghorn antelope in Wyoming and determined that they were not adversely affected by wind facilities. The PEIS concludes that in the longer term, alterations to animal behavior will be localized only to those populations directly affected. Although the PEIS performed some analysis on the larger ecological impacts that wind-based electricity generation facilities may have on ecological processes, it did not analyze the potential effects on a meta-population such as that of the bighorn sheep in the West Mojave (BLM 2005).

- *Geothermal PEIS.* The Geothermal PEIS, finalized in 2008 (BLM & USFS 2008b), presents a limited discussion of the cumulative, region-wide impacts on habitat fragmentation, but these effects were determined to be “minor” and lacked a formal connectivity analysis. Only one alternative discussed any restrictions on development, suggesting it be limited to areas near presently-existing transmission lines. The recommended alternative did not include any restrictions to development (BLM & USFS 2008a).

- *Solar PEIS*. The US Department of Energy and the Bureau of Land Management have begun a PEIS to investigate whether agency-specific programs can administer environmentally responsible large-scale solar energy development in six western states, including California (USDOE & USDOI 2008). The Draft PEIS will be released in August 2009, and the final draft is expected in the summer of 2010. Public comments included a request that the PEIS address ecological concerns in a “holistic manner, with consideration of both the direct and indirect effects.” Commentators specifically requested that impacts to ecological processes be evaluated

> not only in the immediate vicinity of developments and transmission lines, but also beyond it. Comments also specifically requested a discussion of habitat fragmentation, interruption to migration corridors, increased edge effects, and climate change (USDOE & BLM 2008).

The California Energy Commission (CEC) created the *Renewable Energy Transmission Initiative (RETI)* to “identify major upgrades to California’s electric transmission system needed to access renewable energy developments sufficient to meet the state’s energy targets” (RETI Stakeholder Steering Committee 2009). To do this, RETI first determined where large-scale renewable energy development might be built. Over 2,150 potential, proposed, or planned energy projects throughout the state of California were identified and grouped into Competitive Renewable Energy Zones (CREZs).

CREZS may contain wind, solar, biomass and geothermal projects. There are 29 CREZs throughout the state of California, 18 of which exist either partially or wholly within the West Mojave study region used in this analysis (see Figures 7 and 8).

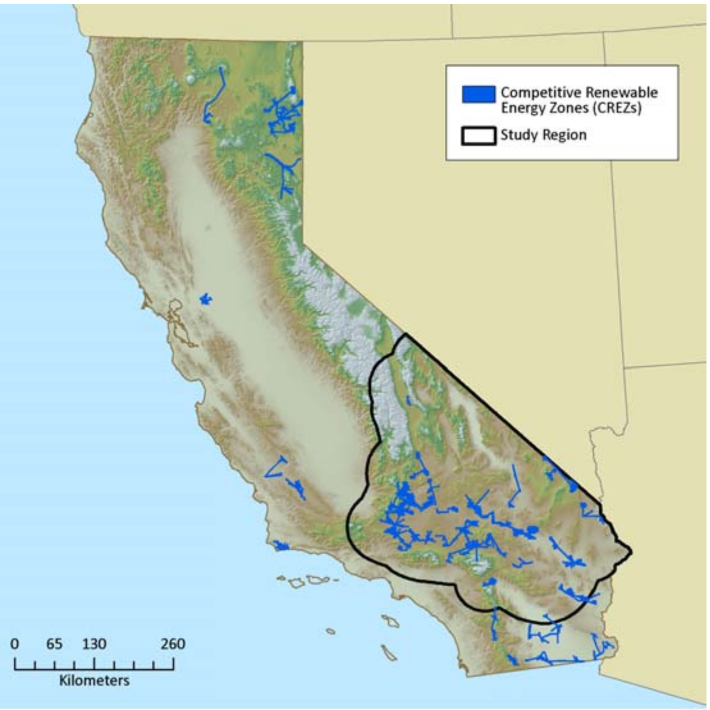


Figure 7. Competitive Renewable Energy Zones (CREZs)
in California and the West Mojave study area.

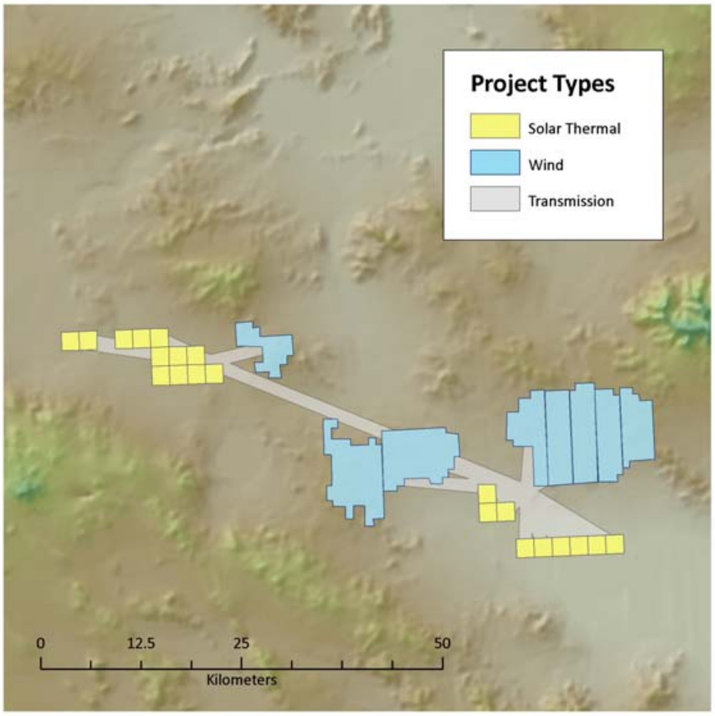


Figure 8. Detail of a Competitive Renewable Energy Zone (CREZ).
An individual CREZ may contain wind, solar, biomass and/or geothermal projects.

To assist planners in determining which CREZs to develop, RETI assigned each CREZ a score for its economic viability and level of environmental concern by averaging the scores of the individual projects contained within. Economic scores were calculated by weighing the cost of development and electricity transmission, the time of day the energy is available, and the contribution to system reliability. The environmental ranking considered the amount of land per unit of energy output, potential conflicts with areas of special environmental concern, potential impacts on wildlife and significant species, and the use of previously disturbed lands. Importantly, however, RETI acknowledges that its connectivity analysis is preliminary (RETI Stakeholder Steering Committee 2009).

In response to Governor Schwarzenegger's 2008 Executive Order pertaining to renewable energy, a Memorandum of Understanding was signed in November 2008 establishing the *Renewable Energy Action Team (REAT),* a cooperative effort between the California Department of Fish and Game, the California Energy Commission, the Bureau of Land Management, and the U.S. Fish and Wildlife Service. This collaboration will help streamline the rising number of applications for renewable energy projects in the Mojave Desert, as well as reduce the processing time typically associated with sighting, developing, permitting, and constructing renewable energy plants. The process also involves creating a Natural Communities Conservation Plan (NCCP) for the Mojave and Colorado deserts referred to as the Desert Renewable Energy Conservation Plan (DRECP). Through the formulation of this plan, REAT hopes to effectively protect natural resources within the Mojave while allowing responsible renewable energy development (Office of the Governor 2008).

7.0 Approach

The overarching goal of this project is to provide recommendations to California's renewable energy planners and conservation organizations concerning the cumulative impacts of large-scale renewable energy development, specifically those related to habitat fragmentation and disruption of species movement and gene flow. Our analytical approach involved four steps:

1. **Determine the expected renewable energy capacity necessary for 2050.** Existing research concerning future energy demand and available renewable technologies was used to establish an estimate of the likely minimum and maximum amount of additional renewable energy capacity that might be needed in 2050.

2. **Develop scenarios describing where this additional capacity might be built.** Present and future baseline scenarios were identified and spatially explicit future development scenarios were designed to meet the estimated minimum and maximum demand scenarios determined in (1).

3. **Model and analyze connectivity of the desert tortoise and bighorn sheep across all scenarios**. A species distribution modeling program called MaxEnt was used to determine the permeability of the study area for both the desert tortoise and bighorn sheep. The probability of movement of these species through the region was then modeled for all scenarios using a program called Circuitscape. The effects renewable energy development on connectivity of these species were analyzed both qualitatively and quantitatively. The connectivity modeling outputs were also used in conjunction with existing genetic data to estimate and analyze changes to migration rates between bighorn sheep populations with and without large-scale renewable energy development.

8.0 Methods

8.1 Determining the Need for Additional Renewable Energy Capacity

The current demand for energy in California is estimated to be 309,868 gigawatt-hours (GWh) per year (CEC 2007). A study by energy analysts at UC Davis (McCarthy *et al*. 2006) projected the combined statewide energy demanded by California's residential, transportation, and commercial sectors as well as the California State Water Project through 2050 under a variety of scenarios. Under one of these scenarios, the study suggested that, although unlikely, potential improvements in efficiency could reduce the state's overall energy demand to 217,000 GWh per year in 2050. Conversely, under another scenario the study predicted that population growth and other factors would increase energy demand to as much as 688,000 GWh per year in 2050.

Assuming California's current goal of generating 33% of its energy from renewable resources by 2020 is still in effect in 2050, then the total amount of renewable energy capacity necessary in 2050 will be between 71,000 GWh and 227,000 GWh (see Table 2). This 2020 Renewable Portfolio Standard (RPS), however, is likely to have increased past 33% by 2050, as another state objective is to reduce carbon dioxide emissions to 80% below 1990 levels by 2050. This is a challenging goal, as limiting today's carbon dioxide emissions just to 1990 levels alone would require a 30% reduction in emissions (CARB 2009). Thus, for California to reach its goal of reducing carbon dioxide emissions to 80% below 1990 levels by 2050, it was conservatively assumed for this analysis that California would increase its RPS to at least 50% by 2050.

Given the minimum and maximum statewide energy demand scenarios projected by McCarthy *et al*. (2006), if it is assumed that 50% of this demand is to be met by energy generated through renewable resources, the state's renewable energy capacity would need to grow to 108,500 GWh per year at the minimum and 344,000 GWh per year at the maximum (see Table 2).

To calculate how much of this expanded renewable energy capacity will need to be met by new, in-state, large-scale renewable energy development, the net short calculation conducted by the Renewable Energy Transmission Initiative (RETI, see Section 6.2.3.2) was duplicated. Specifically, from the predicted renewable demand values of 108,500 and 344,000 GWh per year, the production met by already existing and planned renewable energy developments, as well as the expected contribution from other renewable resources (such as distributed solar from photovoltaic production from California's Solar Initiative [CSI]), and the contribution from economically viable out-of-state renewable electricity production (RETI Stakeholder Steering Committee 2009) was subtracted. Based on this calculation, it was determined that by 2050 new, in-state, large-scale renewable energy development capacity must be expanded to meet approximately 50,000 GWh per year at the minimum and 286,000 GWh per year at the maximum (see Table 3).

Table 2. Projected Renewable Energy Demands for 2050

Energy Demand Scenarios	Total Predicted Demand (GWh)	33% of Predicted Demand (GWh)	50% of Predicted Demand (GWh)
Maximum Demand	688,000	227,040	344,000
Baseline Low Efficiency	450,000	148,500	225,000
Baseline Demand	425,000	140,250	212,500
Baseline high efficiency	350,000	115,500	175,000
Minimum Demand	217,000	71,610	108,500

Source: McCarthy *et al*. 2006

Table 3. Net Short Calculation for 2050

	Minimum Demand Scenario	Maximum Demand Scenario
a. Renewable energy capacity needed assuming 50% Renewable Portfolio Standard	108,500	344,000
b. Existing and planned large-scale renewable energy	36,807	36,807
c. Other renewable resources, (including distributed solar via the California Solar Initiative, anaerobic digestion, landfill gas, small hydro, marine current, and wave power)	6,419	6,419
d. Economically viable out-of-state production	15,010	15,010
e. Net short (a – [b+c+d])	**50,264**	**285,764**

Source: RETI Stakeholder Steering Committee 2009

8.2 Determining Where Additional Renewable Energy Will Be Sited

Once *how much* additional renewable energy must be built was determined, likely scenarios of *where* that capacity would be built were developed. This determination was based on work conducted as part of the RETI analysis.

RETI's analysis examined individual competitive renewable energy zones (CREZs, see Section 6.2.3.2) and sub-CREZs for overall economic return and environmental concern. Although these rankings cannot be combined into a single score, RETI identified six CREZs and sub-CREZs as having the greatest potential economic return and lowest potential environmental concern, and thus as most likely to be built (see Table 4). In fact, three transmission lines are already planned or under construction to service these areas. Each of these six CREZs and sub-CREZs fall within the study region, and combined provide enough generation to more than meet the minimum expected renewable energy demand for 2050 as described above. Due to the format of the data provided by REIT, however, the Imperial North and Victorville CREZs could not be separated into their respective sub-CREZs and so the "low" scenario was expanded to include these CREZs in their entirety (see Figure 9 and Table 4).

Despite the fact that developing these six CREZs would actually produce 32,000 GWh per year beyond the minimum necessary expansion identified above, they were chosen for inclusion in the low scenario for several reasons. While these CREZs ranked highest economically and environmentally, their overall scores were determined by averaging the scores of the projects contained within them. However, due to site-specific environmental and economic concerns it is unlikely that every project in a CREZ will be built. Thus, even if all six of these CREZs are developed, the actual new capacity added should be less than predicted.

Furthermore, the minimum estimate of 50,000 GWh per year of needed additional large-scale renewable energy capacity is highly conservative. The estimate is based on overall electricity demand being reduced by approximately 1/3 of present over the next 40 years. Such a reduction seems unlikely in the face of population growth and shifts in energy priorities (for example, the electrification of California's transportation sector that may be required to meet the state's goal of reducing carbon dioxide emissions to 80% below 1990 levels).

To meet the renewable electricity demand required by the high renewable energy development scenario, it was assumed that every CREZ throughout the state (and thus within the West Mojave) would be built (See Figure 10). This, however, would only result in an additional 207,000 GWh of renewable energy production per year (see Table 4), 79,000 GWh short of the maximum demand identified. The remainder would have to be met through additional CREZ development not yet identified, other renewable sources, or other out of state sources.

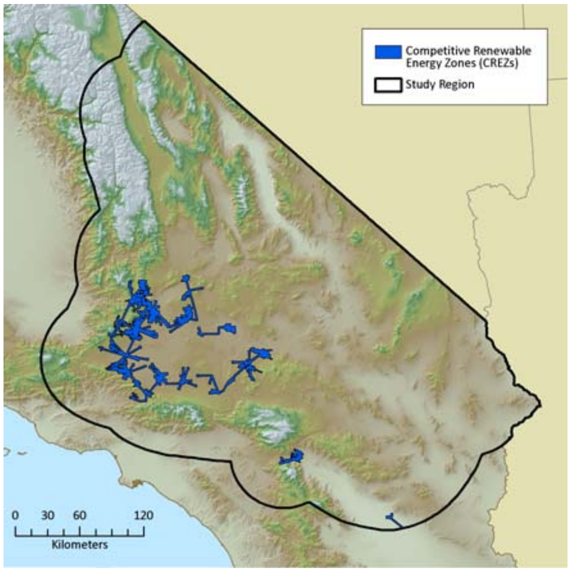


Figure 9. CREZs contained in the low renewable energy development scenario. See Table 4 for specific CREZ names and capacities.

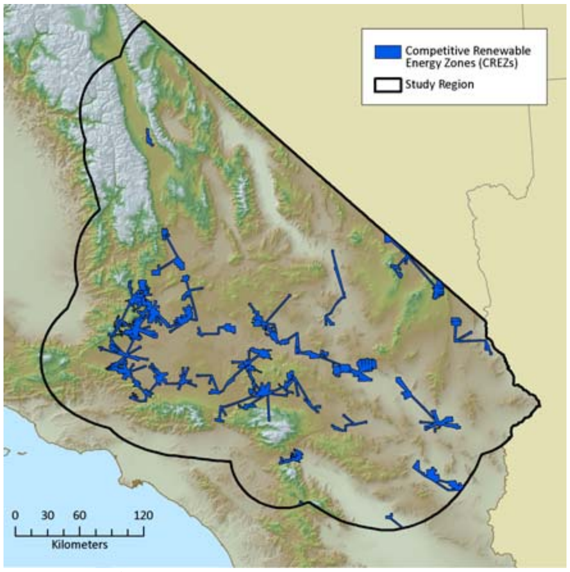


Figure 10. CREZs contained in the high renewable energy development scenario. See Table 4 for specific CREZ names and capacities.

Table 4. Competitive Renewable Energy Zones (CREZs) Contained Within the Low and High Renewable Energy Development Scenarios.

Competitive Renewable Energy Zone (CREZ)	CREZ Capacity (GWh/yr)	Low Renewable Energy Development Scenario	High Renewable Energy Development Scenario
Barstow	5,106		●[‡]
Carrizo North	3,225		●
Carrizo South	6,118		●
Cuyama	847		●
Fairmont	18,318	●[†]	●[‡]
Imperial East	3,991		●
Imperial North – A	10,095	●[†]	●[‡]
Imperial North – B	4,282	●	●[‡]
Imperial South	8,776		●
Inyokern	7,136		●[‡]
Iron Mountain	12,713		●[‡]
Kramer	16,251	●[†]	●[‡]
Lassen North – A	2,086		●
Lassen North – B	3,746		●
Lassen South – A	1,051		●
Lassen South – B	2,379		●
Mountain Pass	6,942		●[‡]
Needles	2,517		●[‡]
Owens Valley	3,433		●[‡]
Palm Springs	2,465	●[†]	●[‡]
Pisgah – A	4,283		●[‡]
Pisgah – B	8,844		●[‡]
Riverside East – A	2,339		●[‡]
Riverside East – B	15,552		●[‡]
Round Mountain – A	1,598		●
Round Mountain – B	705		●
San Bernardino – Baker	2,705		●[‡]
San Bernardino – Lucerne	10,722		●[‡]
San Diego N. Central	702		●[‡]
San Diego South	1,829		●
Santa Barbara	1,121		●
Solano	2,721		●
Tehachapi	25,091	●[†]	●[‡]
Twentynine Palms	1,944		●[‡]
Victorville – A	2,112	●[†]	●[‡]
Victorville – B	2,267	●	●[‡]
Victorville – C	860	●	●[‡]
Total (GWh/yr)		**81,741**	**206,872**

Source: RETI Stakeholder Steering Committee 2009

[†] *Identified by RETI as having greatest economic / lowest environmental concern*

[‡] *Projects developed within the West Mojave in our high renewable energy development scenario*

8.2.1 Developing Modeling Scenarios

In order to isolate the effects of renewable energy versus other development and change that will occur by 2050, all of the modeling done in this analysis was conducted on four scenarios. The four scenarios identified were:

1. The “*Present*” Scenario: including current levels of urban development and associated infrastructure (roads etc.).

2. The “*Future Baseline*” Scenario: including the features of the present scenario as well as additional projected urban development and a simple climate change model for 2050. No large-scale renewable energy development was included in this scenario.

3. The “*Low Renewable Energy Development*” Scenario: including the features of the of the future baseline scenario as well as sufficient renewable energy projects to supply the minimum additional energy capacity needed in 2050 as determined in (1); and

4. The “*High Renewable Energy Development*” Scenario: including the features of the of the Future Baseline scenario as well as sufficient energy projects to supply the maximum additional energy capacity needed in 2050 as determined in (1).

8.3 Modeling Connectivity

In order to understand and conserve ecological processes that depend on connectivity, the effect of landscape features on connectivity must be quantified. Common approaches to predicting connectivity using landscape data include landscape pattern indices and least-cost path models. Connectivity models based on electrical circuit theory are a valuable addition to such approaches because circuit theory can be used to aid in the prediction of movement patterns; measure connectivity between habitat patches, populations, or protected areas; and identify the critical connective elements of a landscape (McRae *et al*. 2008).

8.3.1 Circuit Theory and Ecology

Circuits are networks of nodes connected by electrical components – called resistors – which conduct current. Ohm’s law states that the amount of current (I) that flows through an individual electrical component depends on the amount of voltage applied to the component (V) and the resistance of the component (R), such that I=V/R. Conductance (G) is the inverse of resistance, and represents the ability of an electrical component to conduct current. Effective resistance (Ř) is the resistance between two nodes connected by a network of electrical components and is lowered by the availability of multiple current pathways between the nodes.

In the application of circuit theory to ecological phenomena, a gridded habitat landscape is interpreted as a circuit of electrical components connecting habitat patch or population nodes (focal nodes). The movement of organisms represents the electrical current flowing through this “circuitscape” from one node to another. Resistance symbolizes the opposition of a habitat type to the movement of organisms while the inverse, conductance, is analogous to habitat permeability.

8.3.2 Circuitscape Software

Circuitscape is a software program that predicts connectivity between focal nodes using the principles of circuit theory. The pairwise mode, which was employed in this analysis, requires two inputs:

- A user-defined, gridded landscape in which all grid cells are assigned individual resistance or conductance values based on their expected effect on organism movement or gene flow; and

- A map of focal nodes (points or regions).

In this mode, each unique pair of focal nodes will act as a source-ground pair between which connectivity is modeled. Based on user specifications, Circuitscape calculates either the average resistance or conductance between a cell and its four or eight neighbors to determine the cost of current flow between nodes.

One output from Circuitscape is a cumulative connectivity map showing the total amount of current (current density) flowing through each grid cell in a landscape when all the unique pairwise focal node connections are added together. Current density predicts net movement probability or the number of times random walkers would be expected to move thorough the raster cells if one walker moves from each focal node to each other focal node (McRae *et al*. 2008). Additional outputs from Circuitscape include the effective resistance (resistance distance) or conductance value between each unique pair of focal regions as well as voltage maps which specify the node voltage expected for each focal node pair if 1 amp of current was passed from source to ground.

8.3.3 Benefits of Using Circuitscape

Circuitscape's cumulative map output can be used to identify areas through which there is a high likelihood or necessity of dispersal and to predict the effects of various land use practices on connectivity (McRae *et al*. 2008). In fact, these models are being already being applied to conservation planning for species of concern in rapidly developing landscapes, such as pumas in southern California. Furthermore, the pairwise resistance distances calculated by Circuitscape represent the isolation between nodes and provide a quantitative complement to commonly-used least-cost distance metrics because they integrate all possible pathways while least-cost distances are only measured along a single optimal pathway (which is an unrealistic assumption about organism movement). A major advantage of this property is that when dispersal pathways are lost, the importance of remaining pathways increases and thus they are highlighted (McRae *et al*. 2008). Likewise, the resistance distances calculated by Circuitscape can be used to predict gene flow patterns by relating them to random walks of genes as opposed to individuals. Finally, the use of circuit theory to model ecological connectivity is somewhat intuitive and the implications can be observed and understood readily by nonscientists (McRae *et al*. 2008).

8.3.4 Sensitivity of the Circuitscape Model to Inputs

Because different species respond to landscape features at different scales an appropriate scale for each analysis must be chosen, as must an appropriate extent. While cell size is important, sensitivity analyses revealed that there is considerable robustness of the technique to changes in cell size (McRae *et al*. 2008). However, cell size should remain fine enough to capture landscape elements, corridors, and barriers. Further, there will always be uncertainty in resistance values regardless of the method used to assign them and thus additional uncertainty analyses are encouraged (McRae *et al*. 2008). Other issues include that the symmetrical nature of current flow between a pair of nodes prevents analysis of directionally biased movement and that there is no memory incorporated into the technique so random walkers are truly random which doesn't account for realities such as learned experiences or the increase of mortality with the age of an individual.

8.3.5 Circuitscape Inputs for the West Mojave Analysis

As described above, Circuitscape requires two inputs to model connectivity (see Section 8.3.2). For our analysis, we chose to combine a conductance map with focal regions of importance to the two species of concern.

8.3.5.1 Creating Conductance Maps

To analyze species connectivity, the permeability of the natural and human landscape with respect to the bighorn sheep and desert tortoise was determined in the present and in 2050 with climate change. This was accomplished by modeling habitat suitability for each species across the landscape, then using the suitability values as an approximation for landscape permeability.

The species specific suitability of the natural landscape was modeled using a program called MaxEnt. The human elements within the landscape were then assigned permeability values relative to the minimum habitat suitability and using expert opinion and scientific literature as a guide.

8.3.5.1.1 MaxEnt Software

MaxEnt 3.2.19 (Phillips *et al*. 2006) is a predictive niche modeling program which uses species presence data and environmental variables to model patterns of species occurrence (probability distribution of occurrence) across a landscape. Essentially, MaxEnt compares species presence data to continuous and categorical environmental variables and calculates how the interaction between the different environmental variables contributes to the presence of the species. For example, elevation might be more influential than soil type or vegetation. Ultimately, these calculations converge to create an optimal probability distribution of the species across the landscape.

MaxEnt was used to model the optimal probability distribution of occurrence (“probability of occurrence”) of the desert tortoise and bighorn sheep in the present, as well as under a future scenario for 2050 incorporating climate change. The assumption made by Hagerty (2008)- that probability of occurrence follows habitat suitability, and is a valid approximation of landscape permeability- was followed in this analysis, allowing the resulting distribution maps to serve as part of the inputs into our Circuitscape analysis.

8.3.5.1.2 MaxEnt Inputs for the West Mojave Analysis

For desert bighorn sheep, presence data and data related to elevation, surface roughness, and vegetation in the study region was compiled and used to conduct the MaxEnt analysis. Similarly, for the desert tortoise, presence data was used in conjunction with elevation, surface roughness, vegetation, and soil data.

Following is a description of how presence points and each of the environmental variables were obtained and processed in ArcGIS to create ASCII grids for use in the MaxEnt modeling.

- *Desert bighorn sheep presence data.*
  42 bighorn sheep occurrence points (in latitude-longitude degrees) within the study region were obtained from the California Natural Diversity Database (CDFG 2008), In addition, over 7,000 occurrence points falling within the study region were obtained from the Department of Fish and Game (Lora Konde, personal communication, February 26, 2009).

- *Desert tortoise presence data.*
  46 desert tortoise occurrence points from within the study region were obtained from the CNDDB (in latitude-longitude degrees). In addition, 546 occurrence points were obtained from the US Geological Survey.

- *Elevation.*
  30m (1 degree) US Geological Survey (USGS) Digital Elevation Models (DEMs) were obtained to create an elevation coverage of the study region. Using ArcGIS, the DEMs were converted to raster files with a 300m cell size, projected to the custom Albers projection used for this analysis,and mosaiced together into a single continuous DEM. The resulting continuous DEM was then clipped to the study region and converted to an ASCII grid for use as a continuous environmental variable in the MaxEnt analysis.

- *Topographic roughness.*
  The elevation DEM described above was used to calculate a surface area grid following Jenness (2004). This surface grid was then used to create a surface ratio (surface area / planimetric area) coverage of the study region to serve as an indicator of topographic roughness The resulting topographic roughness raster was converted to an ASCII grid for use as a continuous environmental variable in the MaxEnt analysis.

- *Vegetation.*
  The underlying multi-source land cover layer employed in this analysis was obtained from the California Department of Forestry and Fire Protection (2002). This single data layer is a compilation of the "best available" land cover data from multiple sources (CDFFP 2002), and was created using a cross-walking of classification schemes to compile the various sources into the common California Wildlife Habitat Relationships (CWHR) classification system. Version V02-2, which is the most recent version as of this writing, and which incorporates better data for the Mojave and Northeast Colorado Desert areas (CDFFP 2002) was used in this analysis.

The original layer, containing data for all of California, was projected to the custom Albers projection used for this analysis and clipped to the study region. The data was then resampled from the original 100m cell size to a 300m cell size using ArcGIS's majority resampling technique.

Because desert tortoises and bighorn sheep have different habitat preferences, a raster layer of preferred vegetation was created for each species. Species specific habitat preferences were determined using the CWHR system, which provides suitability values for vegetation classes which are considered suitable for a species. These suitability values range from 0 to 1 and indicate how favorable a specific vegetation type is for the species in question. In order to create a layer of preferred vegetation for each species, the original vegetation data was reclassified such that those vegetation types with a CWHR suitability value listed for the given species were assigned a score equivalent to 100 times the CWHR value, and all other vegetation types were assigned a score of 0. The CWHR values were multiplied times 100 to achieve whole number values for the vegetation raster as opposed to creating a floating point raster. The resulting land cover layers (one each for desert tortoise and bighorn sheep) were converted to ASCII grids for use in the MaxEnt analysis. Because the vegetation classification is rated by preference (i.e. vegetation with a score of 66 is twice as preferable as vegetation with a score of 33), vegetation is considered a continuous environmental variable in the MaxEnt analysis.

- *Soil.*
  State Soil Geographic (STATSGO) soils data compiled by the USDA Natural Resources Conservation Service (NRCS) for California in 1994 was obtained for use in the MaxEnt analysis. STATSGO data are collected as part of the National Cooperative Soil Survey and depict information about soil features on or near the surface of the Earth including soil type and particle size (USDA1994).

  The original STATSGO vector data, covering all of California, was projected to the custom Albers projection used for this analysis and clipped to the study region. The data was then resorted by soil particle size, (resulting in 14 soil types within the study region) and converted to a raster data layer with a 300m cell size.

  The resulting raster was reclassified into 3 classes of soil suitability for the desert tortoise using a study by Andersen *et al*. (2000) as a guide for tortoise preference. Any soil type in the study region with a particle size described as "loamy" according to the NRCS classification scheme was assigned a value of 1, soil types described as “coarse-loamy” were assigned a value of 2, and soil types falling into any other particle size class were assigned a value of 3.Finally, the reclassified soil raster was converted to an ASCII grid for use as a categorical environmental variable in the MaxEnt analysis.

8.3.5.1.3 Training and Testing the MaxEnt Model

MaxEnt uses species occurrence points to generate probability of species occurrence distributions which can be interpreted as a measure of habitat suitability. To examine the predictive ability of the model, occurrence points can be withheld or a separate sample used to later test the model.

Training and testing the bighorn sheep MaxEnt model presented some difficulties. Forty-two occurrence points throughout the West Mojave region were obtained from the California Natural Diversity Database, and all were used to train the model and produce the occurrence probability distribution. Late in the process, an additional 7,000 occurrence points for bighorn sheep were obtained as part of a very large dataset that is currently being compiled by the California Department of Fish and Game (L. Konde, personal communication, February 26, 2009). However, because these points are being compiled sequentially by region, the available subset was spatially biased and only represented a select few locations within the study region. As a result, the CDFG points could not be used to train the bighorn sheep model to make it more robust; they would likely have skewed the model to environmental conditions found in those select locations. Instead, 50 randomly selected occurrence points from the CDFG dataset were used to test the model.

Model training and testing was much simpler for desert tortoise. Approximately 80% of the 548 desert tortoise occurrence points were used to train the model, and the additional 20% were reserved to test the model’s predictive ability.

To quantify the predictive power of the models, MaxEnt generates Receiver Operator Characteristic (ROC) curves, which are graphs of 1- the omission rate vs. the fractional predicted area. Predictive power is indicated both by the area under the curve (AUC) for the test data (as the AUC approaches 1, the model’s predictive power increases), as well as by the consistency between the test and training data ROCs. The model uses this predictive power to assign each grid cell a probability of desert tortoise or bighorn sheep occurrence. The ROC curves for our analyses can be found in the results section below (see Section 8.3.5.1.5).

8.3.5.1.4 Incorporating Climate Change into the MaxEnt Model

The main difference between the present and future probability of occurrence distributions created in MaxEnt is the incorporation of climate change.

Global climate change can be predicted using global climate models (GCMs), which incorporate various greenhouse gas emissions scenarios to predict the range of future temperature changes and precipitation fluctuations across the globe. The United Nations Intergovernmental Panel on Climate Change (IPCC) has developed over 40 emissions scenarios to allow for the uncertainty of future emissions (UNIPPC 2000). Most of these models predict changes looking forward 100 years. The models used by the IPCC project a global surface temperature increase of 1 to 3.5 ºC within this century (UNIPPC 2007). By 2050, the predicted temperatures based on different emissions scenarios lay between 0.5 and approximately 2º C.

For the purposes of this analysis, climate change for 2050 was simulated as a 2ºC temperature increase, which falls at the upper range of increase for 2050 as predicted by the IPCC global warming scenarios (UNIPCC 2007).

Rather than using global climate modeling, however, this analysis chose to incorporate climate change using a more basic method based on the environmental lapse rate.

Using the environmental lapse rate of 6.49º C/1000m, 2ºC temperature increase equates roughly to a 318m increase in elevation. We were able to integrate this change in elevation as a surrogate for temperature increase in the MaxEnt analysis by adding 318m to every cell of the existing DEM using GIS. This new layer, and the other unchanged environmental variables were then used in MaxEnt to train the “future” model. The occurrence probability distribution from this future model incorporating climate change was then projected back onto the original DEM, effectively predicting how desert tortoise and bighorn sheep distributions will change, according to elevation, with a 2ºC temperature increase.

The environmental lapse rate method was used to incorporate climate change instead of using a global climate model projection for several reasons. The main obstacle in using a GCM is a matter of resolution and scale. Since climate models model changes at a global scale, their accuracy at a smaller scale is diminished. The study area employed in this analysis was too small in size to use the global models with confidence. Furthermore, with such a range of emissions scenarios, it would be difficult to choose one specific global model and emissions scenario most suitable for the study area; multiple models would need to be used to obtain a complete picture of possible climate change within the region.

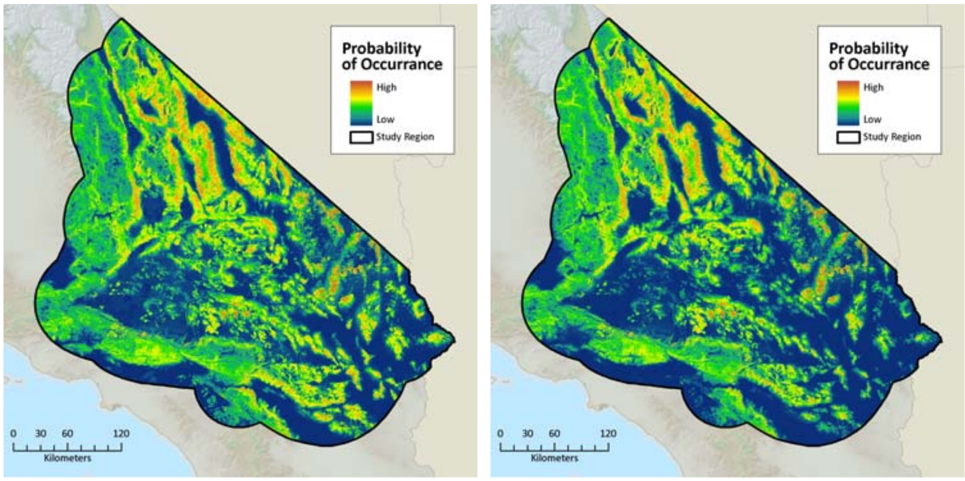
Using the environmental lapse method allowed for climate change modeling without the worry of scale and inaccuracy due to resolution. However, this simplistic technique omitted possible precipitation changes, which could change habitat suitability. Also, future vegetation pattern changes caused by climate change were not included. While others have worked to model future vegetation patterns across the landscape (Bachelet 2001; Lenihan 2003), no studies examine these patterns at a scale small enough for use in this analysis.

8.3.5.1.5 MaxEnt Maps

The final outputs from MaxEnt included present and future species occurrence probability distribution maps, as well as ROC curves that indicate the predictive ability of each model. The final probability of occurrence maps for both the desert tortoise and the bighorn sheep can be found below, rather than in the results section, as they form part of the inputs into the Circuitscape model. The present occurrence probability distributions for each species were used in the present scenario connectivity analysis, while the future distributions incorporating climate change were used in the connectivity analyses for the “future baseline”, “future low renewable energy development”, and “future high renewable energy development” scenarios.

Desert Bighorn Sheep Probability of Occurrence
The bighorn sheep present occurrence probability distribution map (see Figure 11a; for a larger version of the individual map, please see Appendix A) reveals that areas with high probability of sheep occurrence – or highly suitable habitat – seen in yellow and to a lesser extent green, correspond to mountain ranges and areas of high surface roughness. Conversely, areas with ow probability of sheep occurrence – or unsuitable habitat – shown in blue, correspond with desert valleys and areas of mild topographical relief.

The bighorn sheep occurrence probability distribution modeled for 2050 with the incorporation of a 2°C increase in temperature (see Figure 11b; for a larger version of the individual map, please see Appendix B) shows a narrowing of suitable habitat to higher elevations in mountain ranges. Valleys between mountain ranges become especially unsuitable; thus, bighorn sheep populations could become more isolated as it becomes more difficult for dispersers and migrants to traverse the landscape between areas of suitable habitat.



a. Present **b. Future**

Figure 11. Desert bighorn sheep probability of occurrence for present (a) and future (b), as modeled by MaxEnt. Future (2050) assumes a 2 °C increase in temperature due to climate change.

Table 5 illustrates the relative contribution of each environmental variable to the training gain of the MaxEnt model. Surface roughness was by far the largest contributing variable, followed by vegetation type and then elevation.

Table 5. Contribution of each environmental variable to the training gain of the MaxEnt model for the desert bighorn sheep.

Environmental Variable	Percent Contribution
Elevation	73.1
Surface Roughness	18.8
Vegetation	8.1

Figure 12 shows the receiver operating chacteristic (ROC) curve for the bighorn sheep model. The predictive power is relatively strong, especially considering so few points were used to train the model. As mentioned above, the large number of points provided by the Department of Fish and Game could not be used to train the model due to spatial bias, but a random selection of 50 points from this dataset was used to test the model and evaluate its predictive power.

The AUC for the test data is 0.85, indicating relatively strong predictive power, with the test data ROC corresponding fairly closely to the training data ROC. The relative strength of the tested model indicates that the environmental variables chosen (surface roughness, vegetation type and elevation) significantly impact bighorn sheep habitat suitability.

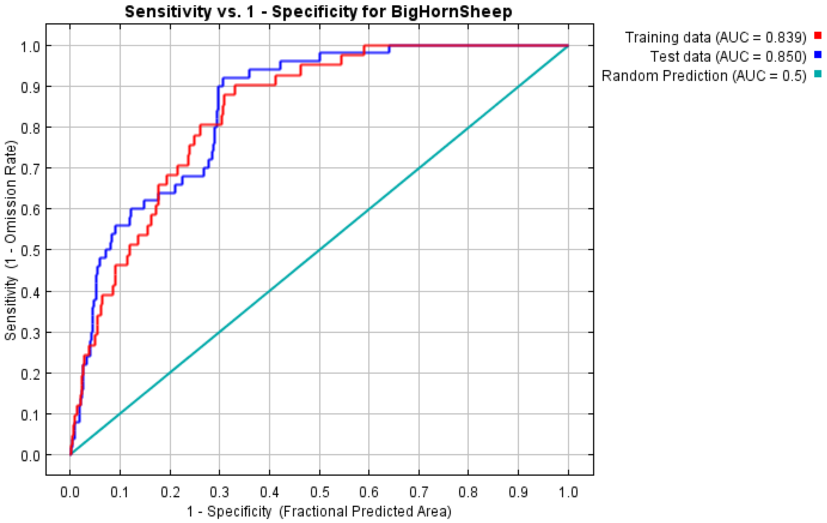
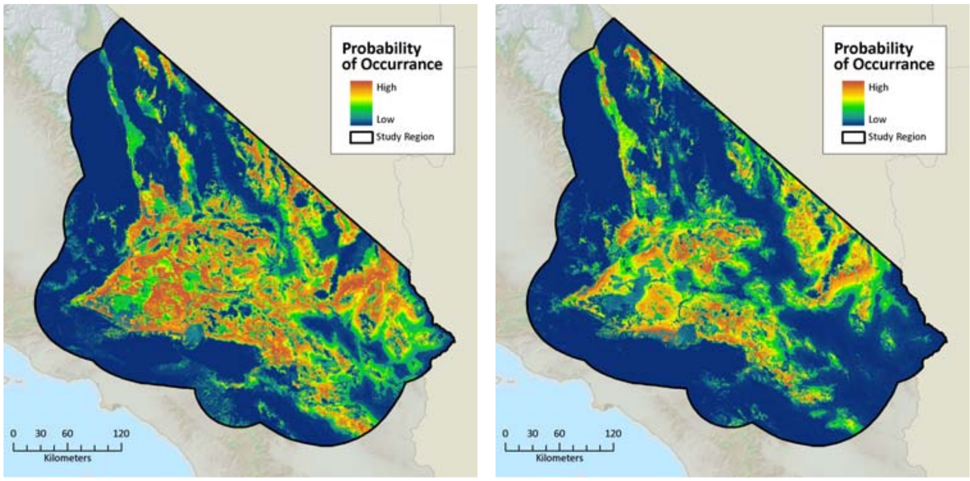


Figure 12. Receiver operating characteristic (ROC) curve for the bighorn sheep MaxEnt model. The stair-step appearance is due to the small number of occurrence points used.

Desert Tortoise Probability of Occurrence

The present and future occurrence probability distribution maps for the desert tortoise are shown in Figure 13 (for larger versions of the individual maps, see Appendix C and D). The probability of occurrence – or suitable habitat – for the desert tortoise in 2050 is noticeably reduced from that of the present, especially in the southwest portion of the West Mojave as well as in the center of the region near Palmdale and Lancaster, where the elevation is near the lower threshold for suitable desert tortoise habitat. These differences make sense given that elevation was the variable that contributed the most to the training of the MaxEnt model with a 37.2 percent contribution to the training gain (see Table 6).



a. Present **b. Future**

Figure 13. Desert tortoise probability of occurrence for present (a) and future (b), as modeled by MaxEnt. Future (2050) assumes a 2 °C increase in temperature due to climate change.

Table 6. Contribution of each environmental variable to the training gain of the MaxEnt model for the desert tortoise.

Environmental Variable	Percent Contribution
Elevation	37.2
Surface Roughness	35.9
Vegetation	26.8
Soils	0.1

Interestingly, previous research shows that the desert tortoise prefers certain soil types – specifically course loamy soils– as these are best for burrowing (Andersen *et al*. 2000). This model, however, was not consistent with such research. This is likely due to the fact that course loamy soils are widespread and throughout the study region. The lack of variation would make this variable less likely to contribute greatly to the model's training gain. This inconsistency could also be due to the fact that occurrence points might be biased towards soils that are less suitable for burrowing because these are locations where the tortoise would be above ground and visible.

The occurrence probability model had strong predictive power, as shown by its ROC curve (see Figure 14). The AUC for the test data used to evaluate the desert tortoise model is 0.87, indicating relatively strong predictive power, with the test data ROC corresponding precisely with the training data ROC.

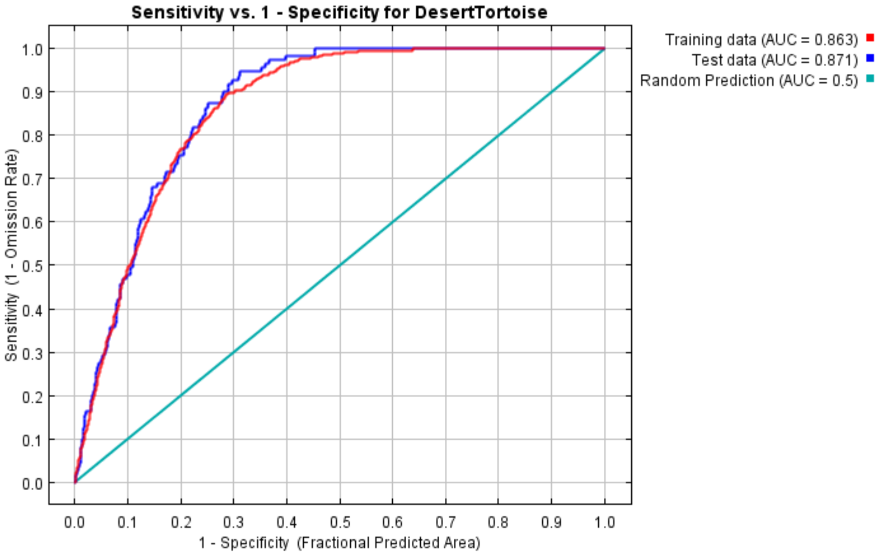


Figure 14. Receiver Operating Characteristic (ROC) curve for the desert tortoise MaxEnt model. The close overlap of the training and test ROC curves indicate the strong predictive power of the model.

8.3.5.1.6 Incorporating the Human Element

The species occurrence probability distribution outputs from Maxent (see Section 8.3.5.1.5) form the base of the conductance map inputs used in Circuitscape. Probability of occurrence was used as an estimate of habitat suitability and the implicit assumption that habitat suitability is an effective approximation of landscape permeability or conductance of species movement was made following Hagerty (2008). This assumption allowed the species occurrence probability values determined by MaxEnt to be employed as conductance values in Circuitscape. However, in order for these maps to accurately represent the four scenarios, the “human” element needed to be incorporated as well. To do so, the Maxent occurrence probability maps were manipulated in GIS to incorporate development and circulation features (roads, railroads, aqueducts, etc.) for each scenario.

For all scenarios, specific conductance values were assigned to development and circulation features and these features were “burned” into the occurrence probability maps in a specific order using ArcGIS’s mosaic tool. Through this technique, any cell overlapped by another valued cell took on the specific value assigned to that overlapping cell. For the renewable energy development scenarios, individual renewable energy projects, and the associated transmission areas were also burned into the occurrence probability maps. The renewable energy projects were assigned a conductance value of zero under the assumption that their design (such as fencing around the project location) would make them completely impermeable to species. The associated transmission areas were assigned a conductance value equivalent to the minimum occurrence probability value assigned by MaxEnt for each species based on the assumption that these areas would be unsuitable for species but not completely impermeable to them.

Because bighorn sheep and desert tortoise are likely to be affected differently by development and circulation features, how these features were treated in the analyzed scenarios varied by species. Following is a summary of the conductance values assigned to the various features for each species (see Tables 7 and 8), as well as a detailed discussion of the how each feature layer was generated.

Table 7. Conductance values of specific landscape features for **desert bighorn sheep** analysis.

Feature	Present Scenario Conductance Value	Future Scenarios Conductance Value	Assigned Value Description
Habitat (MaxEnt output)	3.78E-04 (min) 9.39E-01(max)	4.65E-04(min) 9.39E-01 (max)	Habitat areas were assigned conductance based on MaxEnt modeling (see Section 8.3.5.1)
Current Urban Development	3.78E-04	4.65E-04	Any human development density > 1 unit per 40 acres was assumed to be completely unsuitable, based on a human disturbance distance of 200 m (Hicks & Elder 1979). 400m by 400m = 160,000 m^2 = 39.5 acres. Thus, current urban development was assigned a conductance value equal to the minimum habitat suitability value developed in each MaxEnt model. That is, urban development was only as conductive as the least conductive habitat as modeled in MaxEnt.
US and State Highways	3.78E-04	4.65E-04	Major highways, aqueducts, dams, and canals are usually fenced and therefore largely impassable by desert bighorn sheep (Epps *et al*. 2005; also see Section 5.4.1). Thus, US highways, state highways, and hydrologic infrastructure were assigned conductance equal to the minimum habitat suitability value developed in each MaxEnt model.
Projected Future Urban Growth	N/A	4.65E-04	Project future urban growth was assumed to have a density > 1 unit per 40 acres and was therefore assigned conductance equal to the minimum habitat suitability value developed in each MaxEnt model (see description of current urban development above).
CREZ Outlines (“Transmission”)	N/A	4.65E-04	Transmission areas were assigned conductance equal to the minimum habitat suitability generated by MaxEnt. If these areas were set higher than the minimum, connectivity would have been funneled through these areas in locations where transmission overlaid unsuitable habitat, which is not a realistic representation of behavior.
Energy Projects	N/A	0.00E+00	Energy projects included solar photovoltaic, solar thermal, wind, biomass, and geothermal projects, and were assumed to be impermeable due to the density of human disturbance, likelihood of fencing, and degradation of natural habitat (see Section 6.2). Thus, all energy projects (regardless of type) were assigned zero conductance, and were completely impermeable to species movement.

Table 8. Conductance values of specific landscape features for **desert tortoise** analysis.

Feature	Present Scenario Conductance Value	Future Scenarios Conductance Value	Assigned Value Description
Habitat (MaxEnt output)	4.98E-11 (min) 6.99E-01(max)	8.69E-11 (min) 6.93E-01(max)	Habitat areas were assigned conductance based on MaxEnt modeling (see Section 8.2.5.1.5)
Current Urban Development	4.98E-11	8.69E-11	Assumed to be least suitable habitat due to the density of human disturbance (Edwards 2004; see Section 5.4.2). Thus, current urban areas were assigned conductance equal to the minimum habitat suitability value developed in each MaxEnt model.
US and State highways	4.98E-11	8.69E-11	Highways and other fenced and unfenced larger roads act as barriers to tortoise movement (Boarman *et al*. 1997; see Section 5.4.2). Thus, US highways were assigned conductance equal to the minimum habitat suitability value developed in each MaxEnt model.
US and State highway 400m Buffer	4.98E-07	8.69E-07	Desert tortoise density has been shown to decrease in the areas surrounding highways, up to 400m (Boarman & Sazaki 2006; see Section 5.4.2). Thus, a buffer was created to mimic these effects. Areas surrounding roads, while affecting tortoise density, are assumed to be more permeable than the highway itself; thus they were assigned conductance equal to 10,000 times that of US Highways.
Hydrologic Infrastructure (Canals, Aqueducts, Dams)	4.98E-09	8.69E-09	Fenced areas create barriers to desert tortoise movement (Edwards 2004; see Section 5.4.2). These structures are normally fenced so they were assumed to be highly impermeable. Do not have the vehicle traffic of US and State Highways so were assigned a conductance value 100 times greater.
Railroads	4.98E-08	8.69E-08	Railroads have been shown to obstruct tortoise movement (Edwards 2004). Assumed to be more permeable than highways because lack of vehicle traffic makes railroads more passable (See Section 5.4.2).

Table 8. Conductance values of specific landscape features for **desert tortoise** analysis (continued).

Feature	**Present Scenario Conductance Value**	**Future Scenarios Conductance Value**	**Assigned Value Description**
Local roads and other thoroughfares	4.98E-07	8.69E-07	Roads have been shown to act as a barrier to tortoise movement (Boarman *et al*. 1997, USFWS 2008). Local roads are likely to be fenceless and have less vehicle traffic so they were made more permeable than highways. Because local roads are so prevalent in the landscape, they completely prevented any connectivity in the Circuitscape model if they were given the minimum value, which is not a realistic representation of behavior (tortoises can, in fact, cross local roads). Therefore, the value was increased by an order of magnitude until these barriers allowed for some level of connectivity. Other thoroughfares were assumed to have the same permeability (and therefore conductance) as local roads since the size and type of these roads is not specified (TIGER 2000).
Vehicular Trails	4.98E-06	8.69E-06	Off-road vehicle trails have been found to degrade desert tortoise habitat (USFWS 2008), though they form a less formidable barrier than more highly developed roads with higher traffic levels, so they were assigned conductance 10 times above local roads..
Projected Future Urban Growth	N/A	8.69E-11	Projected future urban growth was assumed to be the same as current urban areas and assigned the same conductance value.
CREZ outlines (“transmission”)	N/A	8.69E-11	Assumed minimum conductance due to density of human disturbance (Edwards 2004), and degradation to habitat (USFWS 2008) from associated maintenance roads. If transmission areas were set higher than the minimum, connectivity would have been funneled through these areas at some locations, which is not a realistic representation of behavior.
Energy Projects)	N/A	0	Energy projects included solar photovoltaic, solar thermal, wind, biomass, and geothermal projects, and were assumed to be impermeable due to the density of human disturbance, likelihood of fencing, and degradation of natural habitat (see Sections 5.4.2 & 6.2) Thus, all energy projects (regardless of type) were assigned zero conductance, and were completely impermeable to species movement.

- ***Present Scenario – Urban Development***
  Cells designated as urban areas were burned directly on to the present occurrence probability distribution grid maps produced by MaxEnt for each species. Urban areas were designated using the Development Footprint data layer (v05_1) produced by the California Department of Forestry and Fire Protection's Fire and Resources Assessment Program (FRAP). The layer is an attempt to spatially define California's combined residential and commercial "footprint of development" (California Department of Forestry and Fire Protection 2005) and includes 2000 Census block data identifying different development densities.

  Using ArcGIS, the original Footprint data layer was re-sampled from 30m grid format to a grid format with a 300m cell size. The resulting grid was then projected to the custom Albers projection used for this analysis, and clipped to the study area.

  The development density classes and corresponding housing densities are listed in Table 9 below.

Table 9. Development density classes and corresponding housing densities.

Density Class	Equivalent Number of Housing Units per Unit Area
Density Class 1	NONE
Density Class 2	LESS THAN 1 UNIT PER 160 ACRES (< 4 / Sq. mi.)
Density Class 3	1 UNIT PER 160 ACRES TO 1 UNIT PER 40 ACRES (4 - 16 / Sq mi)
Density Class 4	1 UNIT PER 40 ACRES TO 1 UNIT PER 20 ACRES (16 - 32 / Sq mi)
Density Class 5	1 UNIT PER 20 ACRES TO 1 UNIT PER 10 ACRES (32 - 64 / Sq mi)
Density Class 6	1 UNIT PER 10 ACRES TO 1 UNIT PER 5 ACRES (64 - 128 / Sq mi)
Density Class 7	1 UNIT PER 5 ACRES TO 1 UNIT PER 1 ACRE (128 - 640 / Sq mi)
Density Class 8	1 UNIT PER 1 ACRE TO 2 UNITS PER ACRE (640 - 1280 / Sq mi)
Density Class 9	2 UNITS PER 1 ACRE TO 5 UNITS PER ACRE (1280 - 3200 / Sq mi)
Density Class 10	GREATER THAN OR EQUAL TO 5 UNITS PER ACRE (>= 3200 / Sq mi)

Adapted from California Department of Forestry and Fire Protection 2003

Urban development is assumed to be least suitable habitat for both species due to the density of human disturbance (Edwards 2004; see Section 5.4.2). Thus, current urban areas were assigned conductance equal to the minimum habitat suitability value developed in each MaxEnt model. That is, urban development was only as conductive as the least conductive habitat as modeled in MaxEnt.

The lowest density at which development begins to impede the movement of bighorn sheep and desert tortoise was estimated through literature review and with expert advice. Any human development density > 1 unit per 40 acres was assumed to be completely unsuitable, based on a human disturbance distance of 200 m (Hicks & Elder 1979). Thus, the minimum density class for the bighorn sheep was set at class 4 (Hicks & Elder 1979; Clinton Epps, personal communication, November 2008). For the desert tortoise it was set at class 7 (Boarman & Sazaki 2006; Kristan, III & Boarman 2003; Ken Nussear & Todd Esque, personal communication, November 2008 – January 2009).

All cells with housing density values greater than or equal to the threshold density designated for each species were included in the “urban” area layer created for that species. These urban areas were then collectively assigned a single conductance value and burned into the present occurrence probability distribution grids for each species. The remaining density classes were assigned as “no data” and thus ended up with the original occurrence probability (conductance) value assigned in the underlying Maxent map.

- ***Present Scenario - Transportation***

  The circulation data used in this analysis were derived from US Census Bureau Tiger 2K (June 7, 2002 Version) information (California Spatial Information Library 2002). The data was obtained in vector format, projected to the custom Albers projection used for this analysis, clipped to the study area, and converted to raster format with a 300m cell size.

  The US Census Bureau classifies these circulation layers into US Highways, State Highways, Railroads, Local Roads, Other Thoroughfare, and Vehicular Trails. Major highways are usually fenced and therefore largely impassable by bighorn sheep (Epps *et al*. 2005; also see Section 5.4.1). Thus, US highways and state highways were assigned conductance equal to the minimum habitat suitability value developed in each MaxEnt model.

  While only US and State Highways were assumed to impact bighorn sheep movement, all classes were assumed to affect the desert tortoise. (Edwards *et al*. 2004, USFWS 2008, Boarman *et al*. 1997; see also Section 5.4.2). As with sheep, US highways and state highways were assigned conductance equal to the minimum habitat suitability value developed in each MaxEnt model. In addition, a 400km buffer was applied to US and State Highways in the desert tortoise scenarios to reflect the distance at which desert tortoises are impacted by highways (Boarman & Sazaki 2006). Local roads are likely to be fenceless and have less vehicle traffic so they were made more permeable than highways. In addition, the prevalence of local roads in the landscape completely prevented any connectivity in the Circuitscape model if they were given the minimum value. Therefore, the value was increased by an order of magnitude until these barriers allowed for some level of connectivity. Other thoroughfares were assumed to have the same permeability as local roads since the size and type of these roads is not specified (TIGER 2000). Railroads have been shown to obstruct tortoise movement (Edwards 2004), but are assumed to be more permeable than highways because lack of vehicle traffic makes railroads more passable (See Section 5.4.2). Off-road vehicle trails have been found to degrade desert tortoise habitat (USFWS 2008), though they form a less formidable barrier than more highly developed roads with higher traffic levels. Thus, off-road vehicle trails were assigned conductance 10 times above local roads.

The roads and buffers were converted to raster format, assigned conductance values unique to road type and species, and burned on top of the Maxent occurrence probability distribution maps for each species.

- ***Present Scenario – Hydrologic Features***
  The US National Atlas Water Feature Line data was used to obtain locations for canals, aqueducts, and dams within the study region. The original California-wide dataset was projected to the custom Albers projection used for this analysis and clipped to the study region. The Water Feature data was sorted into a subset of the original data that included only canals, aqueducts, and dams. This subset was then converted to raster format with a 300m cell size, assigned a specific conductance value for each species, and burned on to the occurrence probability distribution grids for each species.

  Hydrologic features are normally fenced and so create a barriers to movement for both bighorn sheep and desert tortoise movement (Edwards 2004; see Section 5.4.2).

  Finally, the composite gridded conductance maps (incorporating the Maxent occurrence probability distributions as well as urban areas, circulation layers, and hydrologic features) were converted to ASCII files for input into Circuitscape.

- ***Future Baseline Scenario – Urban Development, Circulation Features, and Hydrologic Features***
  The urban2050_ca projected urban development data layer developed by Landis (2002) was used to represent future urban development in 2050. The Landis projections are based on extrapolations of current

population and urban development trends and extend through 2100 (Landis 2002). The data was obtained in vector format, projected to the custom Albers projection used for this analysis, clipped to the study area, and converted to a raster format with a 300m cell size.

The resulting raster data was assigned the same conductance value as that assigned to the urban development in the present scenario (see Tables 7 and 8). This projected urban development for 2050 was burned into the future occurrence probability distributions developed by Maxent for each species. The same circulation and water feature layers used in the present scenario for each species were burned in after this urban development. Due to lack of adequate data, additional layers concerning the planned inland port, planned roads, long distance transmission, or rail projects (e.g. high speed rails) were not incorporated in this future analysis.

The composite gridded conductance maps (incorporating the Maxent occurrence probability distributions as well as current and future urban development, circulation layers, and hydrologic features) were converted to ASCII files for input into Circuitscape.

- ***High and Low Energy Development Scenarios – Renewable Energy Development Infrastructure, Urban Development, Circulation Features, and Hydrologic Features***
  In addition to the features incorporated into the future baseline scenario, the future renewable energy development scenarios also included potential projects and transmission locations as identified by the Renewable Energy Transmission Initiative (RETI) in Competitive Renewable Energy Zones (CREZs) (see Section 6.2.3.2).

  Data layers identifying the locations of CREZs as well as individual biomass, geothermal, solar photovoltaic, solar thermal, and wind projects were obtained from the Renewable Energy Transmission Initiative. The data was obtained in vector format, projected to the custom Albers projection used for this analysis, clipped to the study area, and converted to a raster format with a 300m cell size.

  In order to meet the low energy demand scenario for 2050 utilized in this analysis, it was determined that six CREZs would need to be built, all falling within the study region. In order to meet the high energy demend scenario for 2050 utilized in this analysis, it was determined that all CREZs within California and thus all those within the study area would need to be built (See Section 8.2). Thus, for the low energy demand scenario, the six identified CREZs (including projects and transmission) were isolated and clipped from the complete data set. Similarly, for the high scenario, all of the CREZs falling within the study area were isolated and clipped from the complete data set. Using the reclassification tool, individual projects were assigned a conductance of zero (completely impermeable), while the associated transmission areas were assigned a conductance value equivalent to the minimum occurrence probability value assigned by MaxEnt for each species (see Section 8.3.5.1.2). Note that these transmission areas are only designated between projects within a CREZ and do not include transmission connecting CREZs to urban areas.

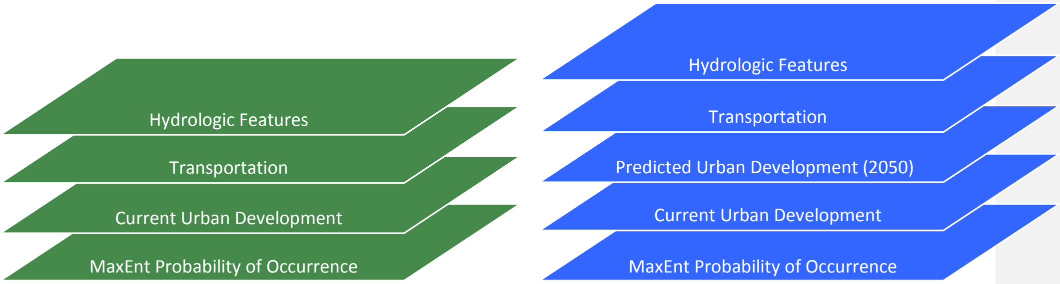
Transmission areas were assigned conductance equal to the minimum habitat suitability generated by MaxEnt for both species due to the expected human disturbance (Edwards 2004), and degradation to habitat (USFWS 2008) from associated maintenance roads. If these areas were set higher than the minimum, connectivity would have been funneled through these areas in locations where transmission overlaid unsuitable habitat, which is not a realistic representation of behavior.

Individual project locations were assumed impermeable due to the density of human disturbance, likelihood of fencing, and degradation of natural habitat (see Sections 5.4.1, 5.4.2, and 6.2) Thus, all energy projects (regardless of type) were assigned zero conductance, and were completely impermeable for both bighorn sheep and desert tortoise.

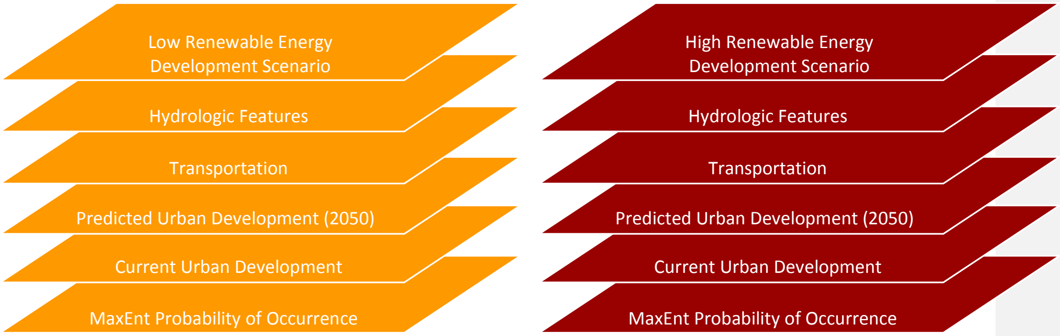
The transmission areas associated with each specific renewable energy development scenario were burned into the “future baseline” map for each species. Lastly, the individual RETI projects were burned into the resulting map to complete the future renewable energy conductance base maps for each species.

The composite gridded conductance base maps (incorporating the Maxent occurrence probability distributions as well as current and future urban development, circulation layers, hydrologic features, energy projects, and transmission areas) were converted to ASCII files for input into Circuitscape.

Figure 15 illustrates schematics for how the Maxent outputs were combined with urban areas, roads, hydrologic features, and renewable energy development for each scenario for use in the Circuitscape analysis.



a. Present **b. Future Baseline**



c. Low Scenario **d. High Scenario**

Figure 15. Construction of Circuitscape Conductance Maps. To create input maps for Circuitscape, MaxEnt probability of occurrence maps were overlaid with varying development, transportation, hydrologic feature, and renewable energy development layers of varying conductance (see Section 8.3.5.1.2).

8.3.5.2 Creating Focal Nodes

8.3.5.2.1 Desert Bighorn Sheep

A bighorn sheep population polygon data layer was obtained in vector format (Clinton Epps, personal communication, November 18, 2008), projected to the custom Albers projection used for this analysis, clipped to the study area, and converted to raster format with a 300m cell size. The resulting raster data was then reclassified such that each of the individual populations received a unique ID between 1 and 69 (see Figure 4).

A pairwise analysis was conducted for all 69 sheep populations for the present and High Renewable Energy Development Scenario, and a more detailed analysis was conducted on eight populations (see Figure 16). The eight populations were chosen based on large population size, representative location (such that they covered distinct parts of the study region), and on the availability of recent genetic data. Comparison of the quantitative outputs from the analyses using 69 and 8 populations provided verification that the connectivity analysis preformed using the 8 populations subset would result in the same values as those obtained for the 8 populations in the analysis preformed with all 69 populations.

For all scenarios, the eight bighorn sheep population polygons shown in Figure 16 were converted to ASCII format for input into Circuitscape. It is important to note, however, that for the high and low renewable energy development scenarios, it was checked and verified that no renewable energy development overlapped with any of these population polygons. Had there been any areas of overlap, they would have been clipped from the population polygons to create an altered set of focal nodes for use in running the renewable energy development scenarios.

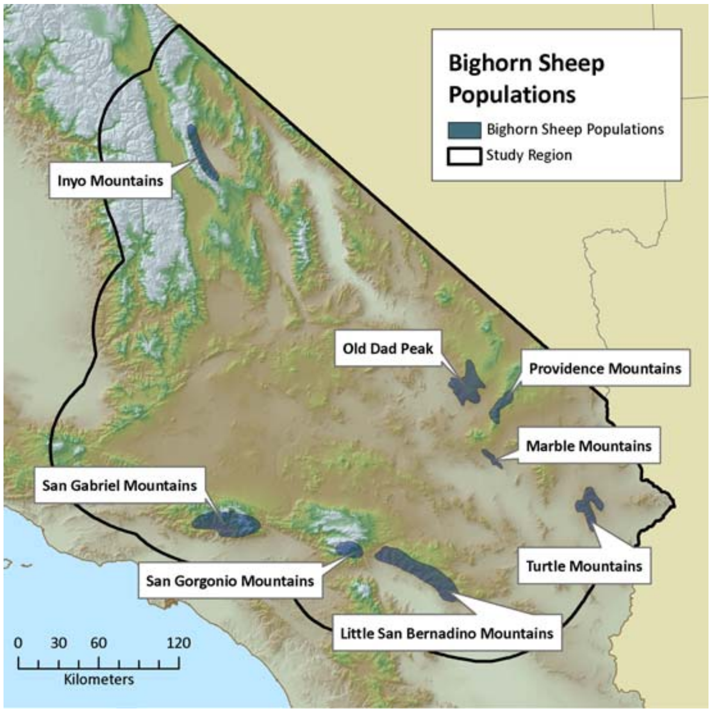


Figure 16. Bighorn sheep population polygons used as nodes for the Circuitscape analysis.

8.3.5.2.2 Desert Tortoise

Unlike bighorn sheep, the desert tortoise population in the study region does not consist of a metapopulation composed of discrete local populations. Instead, thousands of tortoises are spread out across the landscape creating one relatively contiguous Mojave population (Hagerty 2008).

Choosing nodes for Circuitscape from a single population is difficult. Using single points of occurrence as nodes is feasible; however, these points may be biased depending on the methods used to collect them and could fail to represent points of true interest for the focal species. Thus, this analysis was performed using the eight critical habitat areas designated for the species by the California Department of Fish and Game’s 1994 tortoise recovery plan. Although these political designations may change over time, they are home to many of the occurrence points used in the MaxEnt modeling (see Section 8.3.5.1), are generally delineated around highly suitable habitat, and provide a certain level of protection that may become more critical as human development in the West Mojave progresses.

Data depicting the California Department of Fish and Game designated critical habitat for the Desert tortoise was obtained in vector format, projected to the custom Albers projection used for this analysis, clipped to the study area, and converted to raster format with a 300m cell size. The resulting raster data was then reclassified such that each of the eight critical habitat areas in the study region received a unique ID between 1 and 8, and then converted to ASCII format for input into Circuitscape (see Figure 17).

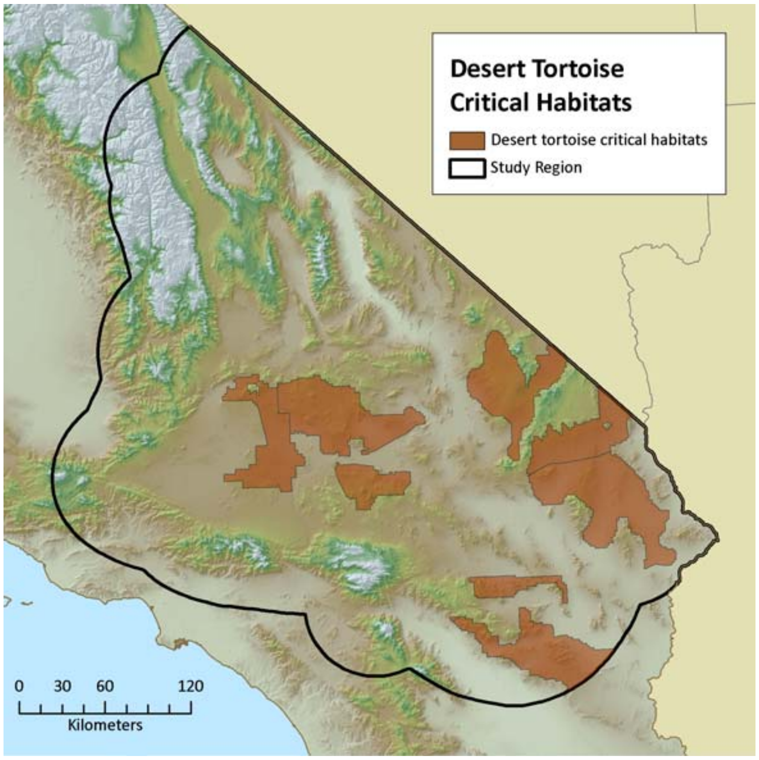


Figure 17. Desert tortoise critical habitats used as nodes for the Circuitscape analysis.

For the present and future baseline scenarios, the critical habitat areas were used unaltered to create the focal node inputs for the Circuitscape analysis. For the high and low renewable energy development scenarios, however, renewable energy development overlapped with certain critical habitats. The areas of overlap were clipped from the critical habitat, and the resulting layers were used to create an altered set of focal nodes for use in running the Circuitscape analysis for the renewable energy development scenarios.

8.3.5.3 Circuitscape Parameters

For the purposes of this analysis, Circuitscape was operated in the pairwise mode with a 4-neighbor cell connection scheme to calculate the average resistances between neighboring cells. The outputs from each analysis included a cumulative current density map (with log10 transformed density values) and resistance distances between each unique pair of focal nodes.

The cumulative current density maps for bighorn sheep and desert tortoise for each scenario can be found in the results section (see Section 9). The following section provides an explanation of how these maps for both species were analyzed in conjunction with one another to determine specific areas important to the connectivity of both species. Section 8.2.6 describes how the resistance distance outputs from Circuitscape were used to analyze gene flow among bighorn sheep populations.

8.3.6 Identifying Areas of Combined Connectivity

Given the often high economic and opportunity costs of preserving open space, it is important to identify areas that can efficiently contribute to the conservation of multiple species. In order to identify areas within the study region important to the maintenance of connectivity for both the bighorn sheep and desert tortoise, a software program called Zonation was employed.

8.3.6.1 Zonation Software

Zonation is a spatial software program that identifies areas important for retaining high habitat quality and connectivity for multiple species (Moelanen & Kujala 2004). It produces a hierarchical prioritization of cells in a landscape in order to identify areas of high conservation priority (Moelanen & Kujala 2004). The prioritization is based on user-defined biological values to each cell in the landscape. The output map is produced by removing the least valuable cells from the landscape one by one, using minimization of marginal loss as the criterion to determine the order in which cells are removed. The definition of loss used for this criterion is set by the user as one of four cell removal rules. The last cells removed represent those with high biological values for all of the focal species analyzed (Moelanen & Kujala 2004).

8.3.6.2 Zonation Inputs for the West Mojave Analysis

Zonation requires two inputs: species distribution maps and a species list file. The distribution maps can be based on many types of distribution data including presence-absence data, abundance data, point distribution data or connectivity data (Moelanen & Kujala 2004). The species list file must contain the names of all the species distribution files to be used in the analysis.

8.3.6.3 Zonation Outputs

Zonation produces a number of outputs including a Weighted Range Size Corrected Richness (wrscr) map. This output is essentially a scoring grid which reports for each cell *i* the quantity:

$$wrsci = \sum_{j} w_j q_{ij}$$

Where:
w_j is the weight of species j; and
q_{ij} is the fraction of the original full distribution of species *j* residing in cell *i* according to the input distribution data (Moelanen and Kujala 2004).

The wrscr-value for a cell can be used as a scoring value where cells with higher wrscr-values are more important.

Zonation Inputs for the West Mojave Analysis

The connectivity outputs from Circuitscape (see Section 9.2) were used as the form of distribution data input into Zonation for each species.

Zonation Parameters

For this analysis, Zonation was run using an additive benefit cell removal rule to prioritize the cells in the study region. This algorithm takes into account the biological values assigned to all species in a given cell, placing the highest priority on cells with the greatest aggregate value. Equal weights were assigned to the bighorn sheep and desert tortoise.

The wrscr output from Zonation was then used to identify areas important for conservation based on high wrscr-values which indicate high aggregate probability of movement for both the bighorn sheep and desert tortoise.
The wrscr output from this Zonation analysis can be found in the results section (see Figure 22).

8.3.7 Modeling Gene Flow

The gene flow analysis conducted in this study employed the Isolation By Resistance (IBR) model (McRae & Beier 2007) to predict how the proposed renewable energy developments included in the renewable energy development scenarios could affect gene flow between bighorn sheep populations. The analogy between electrical and genetic connectivity is as follows: just as wider and more numerous pathways connecting two nodes allow for more current flow, multiple or wider habitat swaths connecting populations allow for more gene flow (McRae & Beier 2007).

The IBR model uses the resistance distance to simultaneously consider all possible pathways connecting population pairs (McRae 2006). This model has been shown to reliably predict the effects of landscape composition on gene flow in artificial population networks (McRae 2006) and real landscapes using genetic data. This model has also been shown to consistently outperform other models used to predict gene flow, such as the Isolation by Distance model and the Least-Cost Path model (McRae & Beier 2007).

For this analysis, the pair-wise resistance distances output by Circuitscape for all 8 bighorn sheep populations analyzed were regressed on pair-wise fixation index (F_{ST}) values for those populations provided by Clint Epps (Clinton Epps, personal communication, November 18, 2008). The resulting linear regression equation was then used to predict pair-wise F_{ST} values for future scenarios. These predicted F_{ST} values were in turn used to calculate predicted migration rates (Nm) using the equation as established by Wright (1921):

$$F_{ST} = \frac{1}{(1+4Nm)} \qquad \text{such that:} \qquad Nm = \frac{1}{(4F_{ST})} - \frac{1}{4}$$

The actual F_{ST} values, resistance distance outputs from Circuitscape, predicted future F_{ST} values, and predicted migrants per generation, as well as the implications for the specific bighorn sheep populations analyzed, can be found in Results Section 9.2.

Genetically distinct populations of desert tortoise in the West Mojave do not correspond to the critical habitat areas that were used as focal nodes in the connectivity modeling preformed for this analysis (Hagerty 2008, Murphy *et al*. 2007). Therefore, real genetic data of the desert tortoise could not be used to verify the model as was done with the bighorn sheep.

9.0 Results

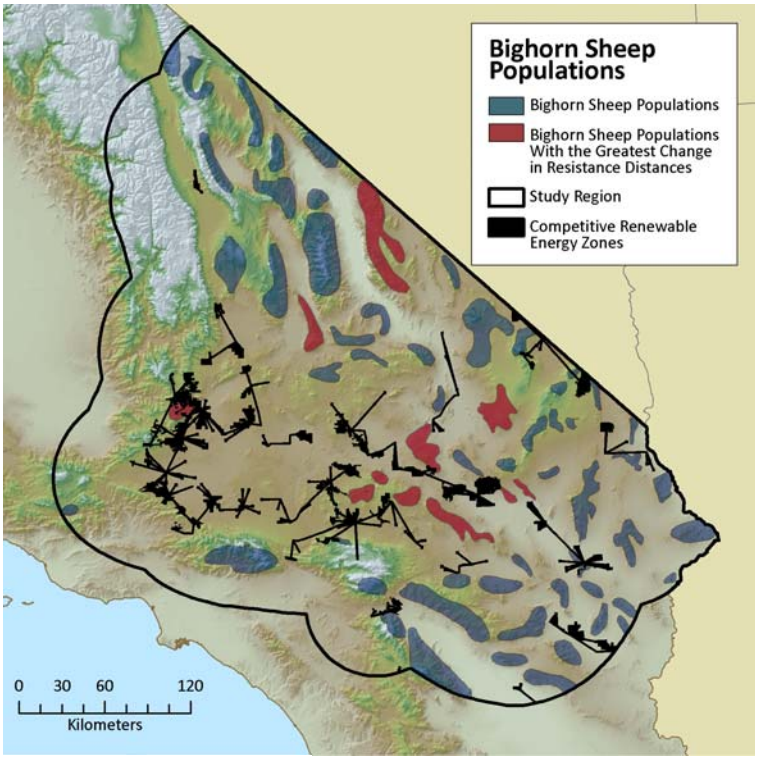
9.1 Renewable Energy Development and Connectivity

The connectivity map outputs from Circuitscape were used to qualitatively identify areas through which there is a high likelihood or necessity of bighorn sheep or desert tortoise movement. To complement this qualitative analysis, the pairwise resistance distances calculated by Circuitscape were used to quantitatively measure connectivity between each unique pair of nodes.

A unique property of the resistance distance metric is that it incorporates multiple pathways between a pair of nodes such that the resistance distance decreases as more connections are added. Thus, this value offers an aggregate measure of both the minimum movement cost and the availability of alternative pathways between two nodes (McRae *et al*. 2008). Generally, the resistance distance between two nodes will be small when those nodes are connected by many paths with low resistance (high conductance), and large when they are connected by few paths with high resistance (low conductance). An increase in the resistance distance between two nodes implies a decrease in the number of connections between those nodes and/or an increase in the length or resistance of the existing connections.

9.1.1 Overall Desert Bighorn Sheep Analysis (Using All 69 Populations)

The analysis included an overall analysis of all 69 bighorn sheep populations for both the Present and the High Renewable Energy Development scenarios (see Appendix M and N). The percent change in resistance distance between the Present and High Scenario was calculated for all unique pairwise population combinations in order to identify overarching patterns in the connectivity of the species across the study region (see Appendix O). The results of this analysis generally revealed an increase in resistance distances between the populations. The majority of the increases in resistance were greater than 100%, and 10 pairwise combinations experienced increases in resistance greater than 500% (see Figure 18 and Table 10).



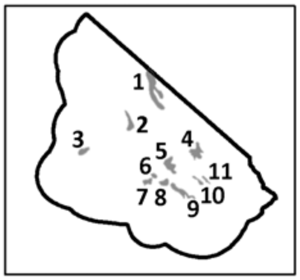


Figure 18. Bighorn Sheep Population with Large changes in Resistance Distances. Resistance distances for the populations in red increased by over 500% between the Present and High Renewable Development Scenario.

(1) Black Mtns; (2) Slate Range; (3) Cache Peak; (4) Old Dad Peak; (5) Cady Mtns; (6) Newberry Mtns; (7) Ord Mtns; (8) Unnamed 2; (9) Bullions Mtns; (10)South Bristol Mtns; (11) Marble Mtns

Table 10. Resistance distance values for Bighorn sheep population pairs with the greatest change from the Present to High scenario

	Resistance Distance Value		
Population Pair	*Present*	*High Scenario*	*% change*
SB/BU	11.4	88.3	674.8
SB/NB	15.2	93.0	513.6
SB/OR	15.5	93.7	503.8
SB/U2	13.2	91.1	590.0
CP/BM	38.6	251.9	553.3
CP/OD	37.5	227.5	507.1
CP/SR	23.6	1215.6	5041.7
BU/CA	11.5	71.2	518.6
BU/MA	13.2	81.2	514.2
U2/CA	11.9	72.8	513.8

BL = Black Mtns; BU = Bullions Mtns; CA = Cady Mtns; CP = Cache Peak; MA = Marble Mtns; NB = Newberry Mtns; OD = Old Dad Peak; OR = Ord Mtns; SB = South Bristol Mtns; SR = Slate Range; U2 = Unnamed 2

Seven populations (Bullions, Cady, Marble, South Bristol, Newberry, and Ord Mountains populations, as well as the Unnamed 2 population) are located in a small cluster in the center of the study region. The renewable energy developments of the High scenario bisect the center of the cluster, effectively eliminating pathways between populations on opposite sides. In order to prevent such large impacts to the connectivity of these populations, renewable energy planners should avoid developing all 3 of the CREZs that together bisect the region, or consider mitigation measures such as preserving a habitat corridor within the cluster.

Another area of concern is the Cache Peak area. Epps et al. (2003) note that the Cache Peak Population went extinct sometime between 1994 and 2003. Because metapopulations are formed by many smaller populations, the disappearance and reappearance of any small individual population is common with, and in fact characteristic of, metapopulations, The Cache Peak area is highly suitable habitat for sheep and as such is an important recolonization area for the metapopulation in years of population growth.

This analysis indicates that the resistance distance between the Cache Peak and Slate Range populations will be over fifty times greater in the High Renewable Energy Development scenario than in the Present scenario—the greatest overall increase in resistance distance by far. The resistance distance between the Cache Peak population and the Black Mountain and Old Dad Peak populations were also more than five times greater for the same scenarios. Qualitative analysis of the location of the Cache Peak area in relation to the renewable energy developments included in the High Renewable Development scenario suggests that the renewable energy developments are likely to be the major cause of the increased resistance to movement to and from the area observed (see Figure 18). Some of the included renewable energy developments are sited directly on top of and surrounding the Cache Peak location and are thus likely to eliminate almost all of the pathways connecting this area to other populations in the study region. Such extensive disruption to connectivity makes recolonization of this area highly unlikely; to preserve connectivity and potential recolonization areas, planners should consider focusing renewable development in other appropriate sites. If these renewable developments are likely to be built despite such effects, it will be critical to incorporate measures into their design that mitigate their effects on connectivity.

One exception to the trend of increasing resistance occurred in the northern portion of the study region within another cluster of populations east of the Sierra Nevada range. Populations in this cluster (Coso Mountain, Deep Springs Range, Dry Mountain/Last Chance Range, Grapevine Mountain, Inyo Mountain, Tin Mountain, Funeral Mountain, Panamint Butte/Hunter Mountain, South Panamint Mountain, Black Mountain, Argus Range, Slate Range, and Rodman Mountain) experienced a mixture of increases and decreases in their pairwise resistance distances with other populations. The decreases in resistance were relatively small, ranging from a maximum decrease of 11% to a minimum decrease of 0.36 %. The increases in resistance observed within this cluster were also relatively small (most were less than 20%) As no renewable energy developments were located between these populations, it is likely that the observed changes in resistance between these populations are due to the shifting with climate change of modeled suitable habitat.

Another exception to the overall trend of increasing resistance occurred in the resistance distances reported between the South White Mountain and Big Maria Mountain populations and all other populations. In both the Present and High Renewable Energy Development scenarios, all the resistance distances involving these two populations were listed as -1.00 and thus the percent change in resistance for connections involving these two populations was reported to be zero. Analysis of the location of the South White Mountain and Big Maria Mountain Populations revealed that they both fall exactly on the outermost boarder of the study region. Due to their location, it is plausible that there was some programmatic error associated with calculating their connectivity to other populations. Thus, the reported results for these two populations should be viewed as incorrect and should not included in further analysis or decision making exercises.

9.1.2 Detailed Analysis using Eight Desert Bighorn Sheep Populations

To analyze bighorn sheep connectivity in more detail, both a qualitative and quantitative analysis of connectivity was preformed on an eight population subset (see Section 8.3.5.2.1 for a discussion of how the subset was chosen). Figure 19a-d presents the connectivity map outputs from this detailed analysis for each scenario (Present, Future Baseline with climate change, Low Renewable Energy Development, and High Renewable Energy Development). This figure is presented for ease of comparison. Larger versions of the maps can be found in Appendices E-H.

9.1.2.1 Present vs. Future Baseline Scenario

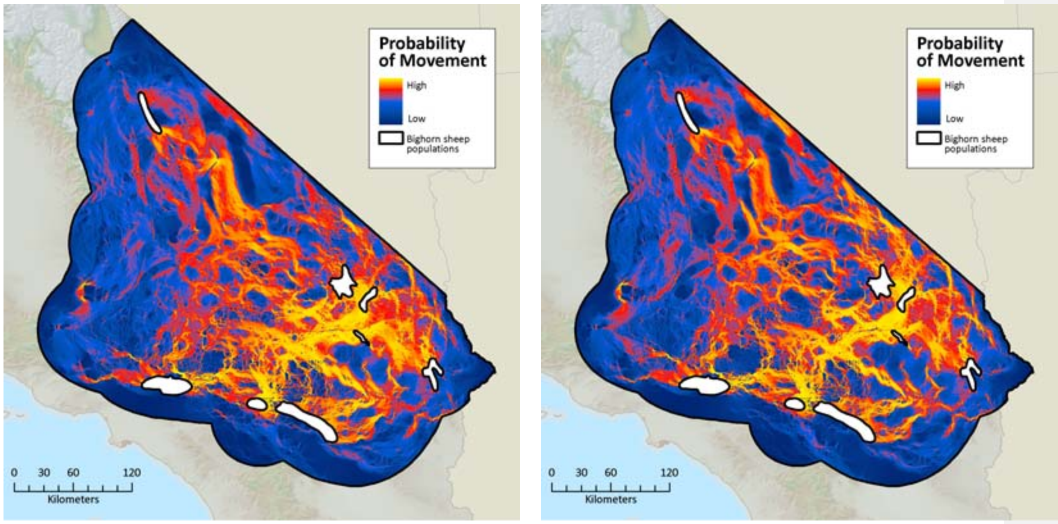
Comparison of the pairwise resistance distances between the bighorn sheep population nodes in the Present and Future Baseline scenarios revealed an increase in all resistance distances (see Table 11). The percent change in resistance distance between these two scenarios was also calculated for each unique pair of population nodes (see Table 11). The greatest percent increase in resistance overall (188%) occurred between the Marble Mountain and Turtle Mountain bighorn sheep populations. In fact, a greater than 100% increase in resistance was observed between the Turtle Mountain population and all other populations except the Inyo, San Gabriel Mountain, and San Gorgonio Mountain populations, which experienced 90%, 55%, and 93% increases in resistance respectively.

9.1.2.2 Low Renewable Energy Development Scenario

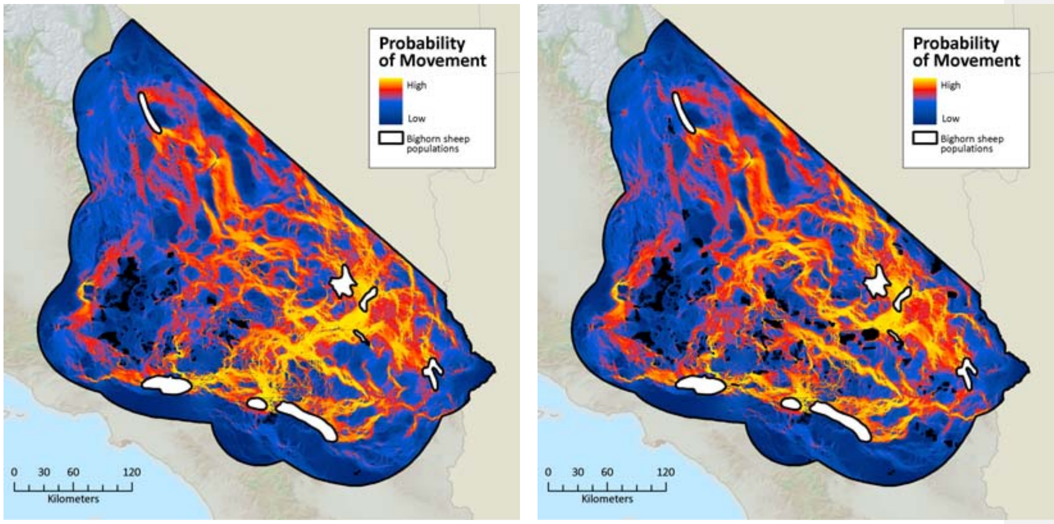
Comparison of the pairwise resistance distances between the populations in the Present scenario and Low Renewable Energy Development scenario illustrated a slightly greater increase in the resistance distances than was observed between the Present and Future Baseline scenarios (see Table 11).

To examine how much of this increase in resistance distance between the Present scenario and the Low and High Renewable Energy Development scenarios could be attributed solely to the renewable energy developments, the relative amount of change in resistance distance attributable to the low and high renewable energy development scenarios was determined (see Table 12) using the following equation:

$$\begin{array}{c}\text{\% change due}\\\text{to renewable}\\\text{development}\end{array} = \frac{\text{\% change between renewable development scenario and future baseline}}{\text{\% change between renewable development scenario and present}}$$



a. Present **b. Future Baseline with Climate Change**



c. Future Low **d. Future High**

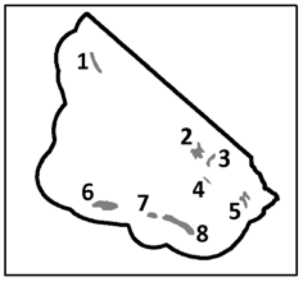


Figure 19 a-d. Bighorn Sheep Probability of Movement

(1) Inyo Mountains; (2) Old Dad Peak;
(3) Providence Mountains; (4) Marble Mountains;
(5) Turtle Mountains; (6) San Gabriel Mountains;
(7) San Gorgonio Mountains; (8) San Bernardino Mountains.

Because the future baseline scenario includes the same climate change and future urban development as the renewable development scenarios, but lacks the renewable energy developments, this value indicates how much of the percent increase in any pairwise resistance distance is due to renewable energy development alone. The higher this value, the greater the impact of renewable energy on the change in pairwise resistance distance.

The result of these calculations illustrates that in the Low Renewable Energy Development scenario, the majority of the percent change in resistance distances between the populations was, in fact, attributable to climate change and future urban development, not renewable energy development. However, while most of the resistance distances between populations in the Low Renewable Development scenario showed only a very sight increase above those of the Future Baseline scenario, a more substantial increase in the resistance distances between the San Gabriel Mountain population and the other populations was observed. More than 40% of this increase in resistance distance could be attributed to renewable energy development, with the largest change attributable to renewable development (72%) occurring between the San Gabriel and the Inyo Mountain populations.

The connectivity map output for the Low Development scenario illustrates that many of the renewable energy developments included in the scenario are concentrated just north and east of the San Gabriel Mountain population. Comparison of this connectivity map to that of the Future Baseline scenario shows that these renewable developments eliminate many of the pathways connecting the San Gabriel population to the other populations analyzed. Furthermore, the probability of movement along a pathway northwest of the San Gabriel population and to the left of the renewable energy developments appears to increase. This increase is likely a result of bighorn sheep being forced into the area as the renewable energy developments cut off previously existing routes. The implications of these effects are two-fold. Either the development of renewable energy projects surrounding the San Gabriel population should not occur at this concentration or, if the developments are to occur, emphasis should be placed on preserving the pathway to the northwest of the population that experiences an increased probability of movement under this renewable development scenario.

Table 11. Resistance distance values for all bighorn sheep population pairs

	Resistance Distance Value				Percent (%) Change in Resistance Distance Value		
Pop. Pair	*Present*	*Future Baseline*	*Low Scenario*	*High Scenario*	Between Present and Future Baseline	Between Present and Low	Between High and Present
OD / SL	68.8	82.4	101.4	137.0	19.75	47.29	99.47
PR / SL	68.8	81.7	100.5	138.0	18.85	46.14	100.11
MA / SL	72.2	90.3	108.7	152.0	24.96	50.49	110.56
TU / SL	85.8	133.3	151.5	191.0	55.33	76.53	122.60
LS / SL	77.1	91.8	109.6	151.0	19.08	42.16	95.39
SG / SL	71.1	78.9	94.2	143.0	10.87	32.48	100.60
PR / OD	3.0	5.0	5.0	5.1	64.11	64.33	68.07
MA / OD	13.3	20.2	20.3	25.6	51.27	51.95	92.21
TU / OD	26.9	65.2	65.4	74.7	142.60	143.22	177.87
LS / OD	29.1	48.2	50.5	93.8	65.56	73.42	222.40
SG / OD	33.8	44.7	47.5	103.0	32.24	40.49	204.98
MA / PR	11.5	15.8	15.8	20.6	37.03	37.38	78.82
TU / PR	25.0	61.5	61.6	70.4	146.19	146.59	182.05
LS / PR	28.0	46.0	48.0	92.0	63.98	71.24	228.27
SG / PR	33.0	42.8	45.3	102.0	29.56	37.18	207.56
TU / MA	23.1	66.6	66.6	75.5	188.01	188.09	226.56
LS / MA	27.4	51.4	53.0	101.0	87.53	93.32	269.42
SG / MA	33.7	49.0	51.0	112.0	45.36	51.42	231.95
LS / TU	37.3	87.3	88.5	126.0	134.23	137.56	238.76
SG / TU	46.4	89.6	91.6	141.0	93.12	97.41	202.88
SG / LS	26.4	29.5	32.1	39.5	11.57	21.35	49.62
SL / IY	71.4	77.7	100.8	125.0	8.88	41.18	74.89
OD / IY	27.9	36.9	38.6	45.5	31.95	38.30	63.02
PR / IY	28.6	37.3	39.3	47.2	30.63	37.81	65.38
MA / IY	34.5	48.0	50.6	64.7	38.81	46.45	87.23
TU / IY	48.4	92.2	95.2	110.0	90.73	96.75	127.57
LS / IY	45.7	62.2	69.3	107.0	36.24	51.81	133.91
SG / IY	47.6	55.7	63.6	113.0	16.99	33.44	136.68

Notes: IY = Inyo Mountains; LS = Little San Bernardino Mountains; MA = Marble Mountains; OD = Old Dad Peak;PR = Providence Mountains; SG = San Gorgonio Mountains; SL = San Gabriel Mountains; TU = Turtle Mountains.

Table 12. Percent of change in resistance distance attributable to renewable energy development in renewable development scenarios for each bighorn sheep population pair.

Pop. Pair	Percent (%) Change in Resistance Distance Value Attributable to Low Scenario	Percent (%) Change in Resistance Distance Value Attributable to High Scenario
OD / SL	48.64	66.93
PR / SL	49.76	68.29
MA / SL	40.46	61.96
TU / SL	17.84	35.32
LS / SL	45.97	67.18
SG / SL	60.01	80.45
PR / OD	0.22	3.55
MA / OD	0.87	29.35
TU / OD	0.18	8.17
LS / OD	6.47	42.59
SG / OD	15.42	63.73
MA / PR	0.69	38.70
TU / PR	0.11	8.00
LS / PR	6.21	43.89
SG / PR	15.82	66.19
TU / MA	0.016	5.91
LS / MA	3.31	36.00
SG / MA	8.10	55.34
LS / TU	1.03	18.69
SG / TU	2.28	28.01
SG / LS	41.07	68.74
SL / IY	72.05	80.96
OD / IY	12.56	37.36
PR / IY	14.54	40.69
MA / IY	11.84%	40.00
TU / IY	3.26%	15.14
LS / IY	22.05%	53.53
SG / IY	42.05%	74.85

IY = Inyo Mountains; LS = Little San Bernardino Mountains; MA = Marble Mountains; OD = Old Dad Peak;
PR = Providence Mountains; SG = San Gorgonio Mountains; SL = San Gabriel Mountains; TU = Turtle Mountains.

9.1.2.3 High Renewable Energy Development Scenario

Comparison of the pairwise resistance distances between populations in the Present and High scenarios illustrated a markedly greater increase in all resistance distances than either the Present and Future Baseline scenarios or the Present and Low Renewable Development scenarios (see Table 11). In addition, calculation of the percent change in the resistance distances between the Present and High Renewable Development scenarios (see Table 11) revealed a greatest overall percent increase (269% between the Marble Mountain and Little San Bernardino Mountain populations).

In fact, a greater than 100% increase in resistance was identified between the Little San Bernardino Mountain population and all others except the San Gorgonio Mountain population and the San Gabriel Mountain population. Similarly, an increase in resistance distance of more than 100% was observed between the San Gorgonio Mountain population and all other populations excluding the Little San Bernardino Mountain population.

Calculation of the relative impact of renewable energy developments in the High scenario revealed that more than 50% of the percent increase in resistance distance between the Little San Bernardino Mountain population and the Inyo Mountain population could be attributed to renewable developments. Additionally, more than 50% of the increase in resistance between the San Gorgonio Mountain population and all other populations except the Turtle Mountain population could also be attributed to the renewable developments in the scenario.

These results are explained by the fact that in the High Renewable Development scenario, a group of renewable developments running from north to south bisects the lower central portion of the study region falling between the San Gabriel, San Gorgonio, and Little San Bernardino Mountain populations in the west and the other populations in the east. Examination of the connectivity map output for this scenario shows that these renewable developments almost completely eliminate many of the pathways linking the populations on the west side of the study region to those on the east side.

To avoid these significant impacts to connectivity, renewable energy planners should strongly consider forgoing the development of one of the CREZs, or at the very least some of the individual projects, in the group that bisects the center of the study region. Alternatively, measures to mitigate the cumulative effect on bighorn sheep connectivity should be incorporated into regional planning efforts. For example, a bighorn sheep wildlife corridor allowing movement of individuals from the populations in the west to those in the east (and vice versa) could be critical to the survival of the species.

9.1.3 Impacts of Climate Change and Renewable Energy Development on Gene Flow in Eight Populations of Desert Bighorn Sheep

The combined effects of climate change, future urban development**,** and renewable energy development considerably increase the effective resistance, and therefore the predicted genetic distance, between most of the populations of bighorn sheep that were analyzed. Several populations are at risk of genetic isolation as predicted migration rates fall below one migrant per generation. Large-scale renewable energy development is likely to have a negative impact on connectivity between these populations.

9.1.3.1 Genetic Distance Predicted by Resistance Distance

The effective resistance distances from the Circuitscape model are highly correlated ($P < 0.001$) with genetic distances between the eight sheep populations analyzed (see Figure 20). Genetic distance is measured by pairwise F_{ST} values, a measure of population differentiation based on genetic data. The regression also has a relatively strong predictive power ($R^2 = 0.625$). These results validate the Circuitscape connectivity model through genetic evidence and provide the capability to predict future genetic distances and migration rates between bighorn sheep populations in order to assess the impact of climate change, future urban development, and large-scale renewable energy on connectivity within the bighorn sheep metapopulation.

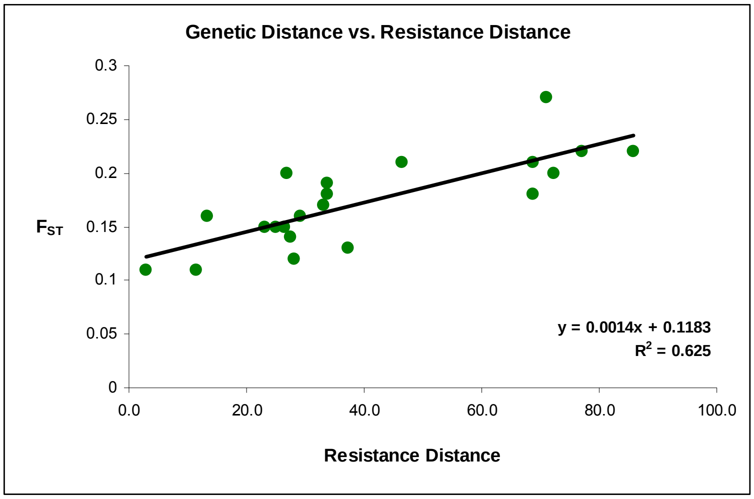


Figure 20. Regression of resistance distance vs. pairwise F_{ST} for bighorn sheep (N=21). This regression equation was used to predict future F_{ST} values for the 8 populations analyzed.

9.1.3.2 Present vs. Future Baseline

The results of the genetic analysis preformed in this study predict that gene flow between most of the 8 bighorn sheep populations will be reduced with future climate change (see Table 13). The Little San Bernardino, Turtle, and Providence Mountains populations are predicted to have the highest decrease in gene flow due to climate change and urban development in the West Mojave. The mean pairwise migration rate (*Nm*) for these populations is reduced by 24-32% and falls below 1 for the Turtle Mountains population. These reductions are likely due to the topography of where these populations exist. Mountains ranges that are near the low elevation threshold of suitable habitat for bighorn sheep will become less, or completely unsuitable with increased temperatures. Also, populations in mountains that are surrounded by low-elevation valleys will become more genetically isolated as fewer migrants are able to traverse these areas and introduce new genes.

The San Gorgonio, Old Dad, and San Gabriel Mountains populations have the smallest reduction in mean *Nm* at 2%, 7%, and 17%, respectively. The migration rate between the San Gabriel and San Gorgonio populations is in fact predicted to increase by 25%, indicating an expansion of suitable habitat between these populations with climate change. These ranges are least affected by climate change and urban growth and can serve as climate refugia for bighorn sheep in the future if they remain well-connected to other populations in the region.

9.1.3.3 Low Renewable Energy Development Scenario

The Low Renewable Energy Development scenario affects the San Gabriel population, which is largely surrounded by development, the most. The mean *Nm* of this population is presently calculated to be slightly less than 1, a well established minimum for maintaining adequate gene flow (Mills & Allendorf 1996), so it is particularly vulnerable to genetic isolation. Migration rates between the San Gabriel population and all other populations analyzed are reduced in the Low Renewable Energy Development scenario by 11-13% from the Future Baseline scenario, so these changes are solely attributable to renewable energy development. This reduction in gene flow puts the San Gabriel population at a higher risk of genetic isolation in the future. The results indicate that when bighorn sheep populations are surrounded by large-scale renewable energy development, gene flow is predicted to decrease significantly, and in the case of the San Gabriel population, particularly vulnerable populations are put at a high risk of genetic isolation.

9.1.3.4 High Renewable Energy Development Scenario

The High Renewable Energy Development scenario reduces the migration rates between the San Gabriel population and populations in the west even further. The migration rate between the San Gabriel and Turtle populations under this scenario falls to 0.4 (well below the established threshold of 1), while the mean *Nm* for the San Gabriel population falls to 0.51. This analysis suggests that the San Gabriel population is at high risk for genetic isolation. As the largest population, San Gabriel acts as an important source of dispersers and re-colonizers, so its isolation is likely to affect the bighorn metapopulation as a whole.

The High Renewable Energy Development scenario exacerbates the decreasing migration rates caused by climate change between the Little San Bernardino population and the Old Dad, Providence, Marble, and Turtle populations. The mean *Nm* value for the Little San Bernardino population in the High Renewable Energy Development scenario is also 0.75, suggesting that in addition to the San Gabriel population, another large sheep population in the region is at high risk of genetic isolation. The migration rates between the Little San Bernardino population and the Old Dad, Providence, Marble, and Turtle populations to the northeast decrease from 24% to 33% from the Future Baseline scenario to the High Development scenario. These changes are caused by a large band of renewable energy development in the High scenario that runs between these populations from the northwest to the southeast, significantly obstructing migration from the Little San Bernardino population to those in the northeast (see Figure 19d).

The migration rate between the Little San Bernardino and San Gabriel populations, the two largest in the region, is predicted to decrease by 33% from 0.76 in the Future Baseline scenario to 0.51 in the High Renewable Energy Development scenario, indicating that development can have a significant impact on the sheep metapopulation in the West Mojave by significantly disrupting connectivity between these two populations.

Table 13. Resistance distance and predicted pair-wise F_{ST} and *Nm* values for all population pairs.

	Present			Future Baseline			Low Renewable Energy Development			High Renewable Energy Development		
Pop. Pair	*R*	F_{ST}	*Nm*	*R*	F_{ST}	*Nm*	*R*	F_{ST}	*Nm*	*R*	F_{ST}	*Nm*
OD / SL	68.8	0.21	0.94	82.4	0.23	0.82	101.4	0.26	0.71	137.0	0.31	0.56
PR / SL	68.8	0.18	1.14	81.7	0.23	0.82	100.5	0.26	0.72	138.0	0.31	0.55
MA / SL	72.2	0.2	1.00	90.3	0.24	0.77	108.7	0.27	0.67	152.0	0.33	0.51
TU / SL	85.8	0.22	0.89	133.3	0.30	0.57	151.5	0.33	0.51	191.0	0.39	0.40
LS / SL	77.1	0.22	0.89	91.8	0.25	0.76	109.6	0.27	0.67	151.0	0.33	0.51
SG / SL	71.1	0.27	0.68	78.9	0.23	0.84	94.2	0.25	0.75	143.0	0.32	0.53
PR / OD	3.0	0.11	2.02	5.0	0.13	1.75	5.0	0.13	1.75	5.1	0.13	1.74
MA / OD	13.3	0.16	1.31	20.2	0.15	1.46	20.3	0.15	1.45	25.6	0.15	1.37
TU / OD	26.9	0.2	1.00	65.2	0.21	0.94	65.4	0.21	0.94	74.7	0.22	0.87
LS / OD	29.1	0.16	1.31	48.2	0.19	1.10	50.5	0.19	1.07	93.8	0.25	0.75
SG / OD	33.8	0.18	1.14	44.7	0.18	1.13	47.5	0.18	1.10	103.0	0.26	0.70
MA / PR	11.5	0.11	2.02	15.8	0.14	1.53	15.8	0.14	1.53	20.6	0.15	1.45
TU / PR	25.0	0.15	1.42	61.5	0.20	0.97	61.6	0.20	0.97	70.4	0.22	0.90
LS / PR	28.0	0.12	1.83	46.0	0.18	1.12	48.0	0.19	1.10	92.0	0.25	0.76
SG / PR	33.0	0.17	1.22	42.8	0.18	1.15	45.3	0.18	1.13	102.0	0.26	0.71
TU / MA	23.1	0.15	1.42	66.6	0.21	0.93	66.6	0.21	0.93	75.5	0.22	0.87
LS / MA	27.4	0.14	1.54	51.4	0.19	1.06	53.0	0.19	1.05	101.0	0.26	0.71
SG / MA	33.7	0.19	1.07	49.0	0.19	1.09	51.0	0.19	1.07	112.0	0.28	0.66
LS / TU	37.3	0.13	1.67	87.3	0.24	0.79	88.5	0.24	0.78	126.0	0.29	0.60
SG / TU	46.4	0.21	0.94	89.6	0.24	0.78	91.6	0.25	0.76	141.0	0.32	0.54
SG / LS	26.4	0.15	1.42	29.5	0.16	1.32	32.1	0.16	1.28	39.5	0.17	1.19
SL / IY	71.4		*	77.7	0.23	0.85	100.8	0.26	0.71	125.0	0.29	0.60
OD / IY	27.9		*	36.9	0.17	1.22	38.6	0.17	1.20	45.5	0.18	1.12
PR / IY	28.6		*	37.3	0.17	1.22	39.3	0.17	1.19	47.2	0.18	1.11
MA / IY	34.5		*	48.0	0.19	1.10	50.6	0.19	1.07	64.7	0.21	0.95
TU / IY	48.4		*	92.2	0.25	0.76	95.2	0.25	0.74	110.0	0.27	0.67
LS / IY	45.7		*	62.2	0.21	0.97	69.3	0.22	0.91	107.0	0.27	0.68
SG / IY	47.6		*	55.7	0.20	1.02	63.6	0.21	0.96	113.0	0.28	0.65

Notes: R *is generated by Circuitscape;* F_{ST} *generated by Epps et al. (2005), predicted by the linear regression equation.* $F_{ST} = 0.1183 + 0.0014R$. Nm *calculated by* [$F_{ST} = 1 / (1 + 4\,Nm)$] *(Wright 1921). IY = Inyo Mountains; LS = Little San Bernardino Mountains; MA = Marble Mountains; OD = Old Dad Peak;PR = Providence Mountains; SG = San Gorgonio Mountains; SL = San Gabriel Mountains; TU = Turtle Mountains.*

* Present pair-wise F_{ST} are real genetic data generated by Epps *et al*. 2005. These values were not available for the Inyo population, so present *Nm* values could not be calculated.

9.1.4 Desert Tortoise

For the analysis of desert tortoise connectivity, the 1994 California Department of Fish and Wildlife-designated critical habitat regions for the species were used as focal nodes (see Figure 17). Figure 21a-d presents the connectivity map outputs for each scenario (Present, Future Baseline with climate change, Low Renewable Energy Development, and High Renewable Energy Development). This figure is presented for ease of comparison. Larger versions of these maps can be found in Appendices I-L.

9.1.4.1 Present vs. Future Baseline Scenario

Comparison of the pairwise resistance distances between critical habitat areas in the Present and Future Baseline scenarios revealed an increase in all resistance distances (see Table 13) except those between critical habitat areas 1 and 4, and 7 and 8. Calculation of the percent change in resistance distance revealed that the increases were relatively minor (less than 10% for all but four pairwise connections).

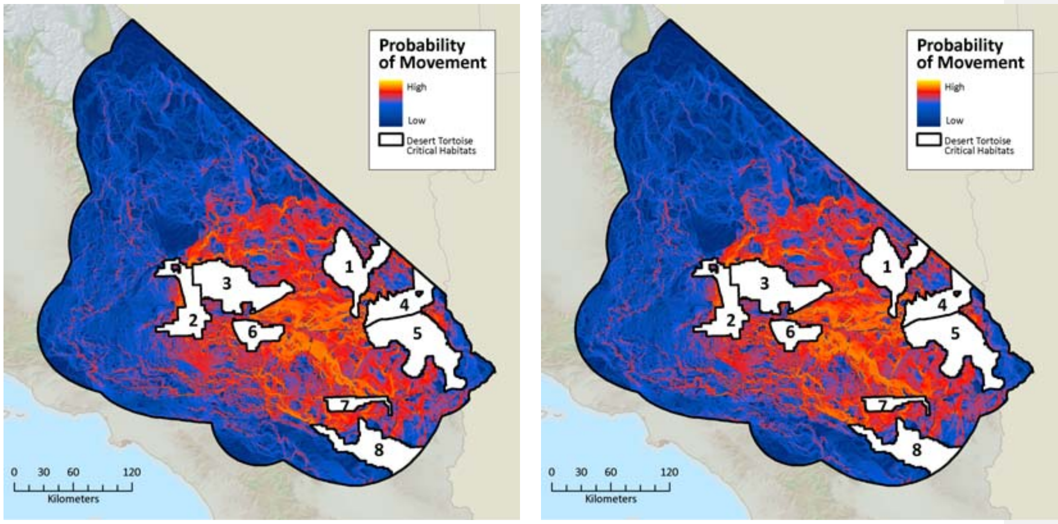
The largest percent increase in resistance overall was 44% and occurred between critical habitats 3 and 4. This increase in connectivity was observed across all scenarios and calculation of the contribution of renewable energy to changes in the connectivity between this pair of habitats suggested that the changes were completely unrelated to renewable energy development. This indicates that the increase in connectivity between this pair of habitats is likely due to the shifting of suitable habitat areas under climate change. Conversely, the largest decrease in effective resistance (88%) occurred between critical habitat areas 1 and 4, which are located in very close proximity. It is plausible that the small habitat patch separating them might become more conducive to tortoise movement under climate change as simulated in this analysis, resulting in the decreased resistance.

9.1.4.2 Low Renewable Energy Development Scenario

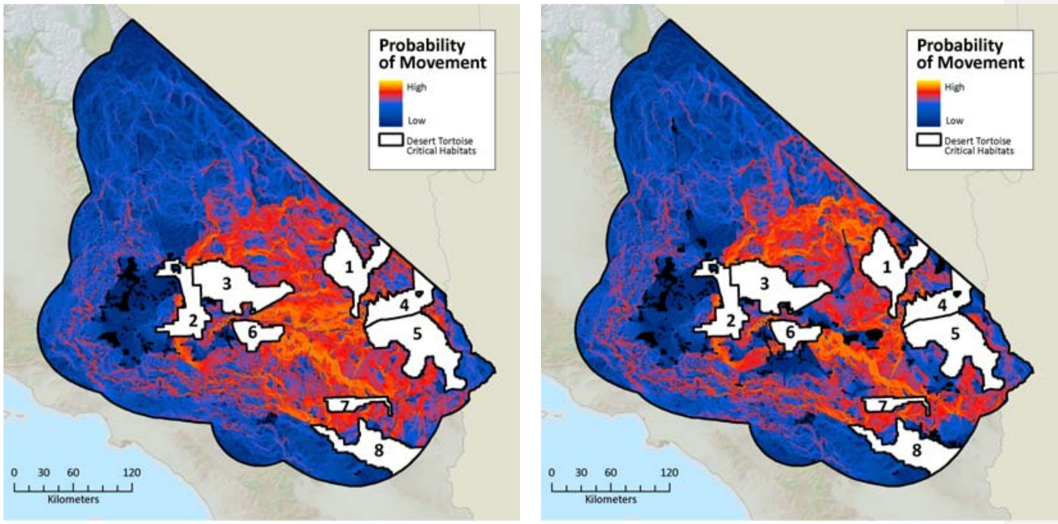
Comparison of the pairwise resistance distances between the critical habitats in the Present and Low Renewable Energy Development scenarios illustrated a pattern of change in resistance distances similar to that observed between the Present and Future Baseline scenarios, but occurring to a slightly greater degree (see Table 13). The largest overall percent increase in resistance (48%) was observed between critical habitats 3 and 4. The majority of the increases in resistance distance were minor, with a larger than 10% increase in resistance distance being detected between only a few critical habitat pairs. These pairs included those between critical habitat 3 and all other critical habitats except critical habitat 1, and between critical habitat 2 and all other habitats except habitat 1.

Although the increases in resistance were relatively minor, calculation of how much of these observed increases could be attributed solely to the renewable energy developments included in the scenario indicated that renewable energy development played a large role in the increases in resistance. The largest change attributable to renewable energy development (83%) occurred between critical habitats 6 and 8 (see Table 14). Similarly, more than 70% of the increase in resistance between critical habitats 7 and 8 and habitats 1, 2, 4, and 6 was attributable to the renewable energy developments included in the scenario.

Qualitative analysis of the connectivity map for this scenario suggests that the increase in resistance between habitats 6 and 8 is likely caused by the two renewable energy developments in the scenario that fall to the left of these critical habitats and which appear to interrupt some pathways between them. A majority of the renewable energy development in this scenario occurs to the west and south of critical habitat 2 explaining the large portion of the increase in resistance for that population that can be attributed to renewable development. Additionally, several CREZs actually cause direct habitat loss in three critical habitats. The disturbances are located in the north of habitat 2, the southern sides of habitat 3, and the northwest corner of habitat 6. These direct impacts to critical habitat are likely to be detrimental to the desert tortoise and should be avoided by prioritizing the development of other CREZs or by excluding from development specific projects that fall within critical habitat areas.



a. Present **b. Future Baseline with Climate Change**



c. Future Low **d. Future High**

Figure 21 a-d. Desert tortoise probability of movement.

Table 14. Resistance distance values for all desert tortoise critical habitats.

	Resistance Distance Value				**Percent (%) Change in Resistance Distance Value**		
Habitat Pair	*Present*	*Future Baseline*	*Low Scenario*	*High Scenario*	Between Present and Future Baseline	Between Present and Low	Between High and Present
1/2	95582.49	97950.54	168735.60	168735.60	1.63076	2.47750	76.53402
1/3	54698.96	58443.92	58517.01	135705.62	6.84649	6.98010	148.09542
1/4	177.349	21.27	21.27	21.27	-88.00857%	-88.00857	-88.00564
1/5	222579.71	222827.90	223314.87	249972.95	0.11151	0.33029	12.30716
1/6	2585215.52	2696744.88	2826042.35	5848489.68	4.31412	9.31554	126.22832
1/7	2623996.35	2732079.61	3107168.74	6991263.94	4.11903	18.41361	166.43573
1/8	2647089.70	2755430.38	3132571.72	7031943.84	4.09282	18.34022	165.64811
2/3	0.032	0.05	0.046	0.046	43.39081	43.42574	43.42575
2/4	2823901.86	2935184.08	3157440.53	4440890.16	3.94073	11.81127	57.26078
2/5	2920803.54	3034281.72	3271369.25	4563178.57	3.88517	12.00237	56.23025
2/6	3551915.85	3772132.19	4032955.88	5949468.59	6.19993	13.54311	67.50027
2/7	3617825.70	3833178.59	4720651.27	7494749.11	5.95255	30.48310	107.16170
2/8	3637466.13	3853026.09	4742710.44	7533550.86	5.92610	30.38501	107.10986
3/4	810737.83	1172188.33	1199127.25	4435394.69	44.58291	47.90567	447.08125
3/5	916871.38	1277875.02	1309647.84	4560548.74	39.37342	42.83877	397.40333
3/6	2792700.19	3075603.80	3248492.28	6357013.53	10.13011	16.32084	127.62965
3/7	2836916.76	3118684.03	3626285.89	7802764.76	9.93217	27.82490	175.04384
3/8	2859319.31	3140957.73	3650695.59	7841857.30	9.84984	27.67709	174.25609
4/5	41744.67	41750.61	41759.22	47607.63	0.01422	0.03484	14.04481
4/6	2595980.74	2661812.48	2716914.08	7021132.62	2.53591	4.65848	170.46166
4/7	2605231.70	2668591.00	2837926.58	7682227.40	2.43200	8.93183	194.87694
4/8	2631651.83	2695225.39	2865966.83	7724093.78	2.41573	8.90372	193.50743
5/6	2578569.76	2639654.49	2690952.14	6935280.28	2.36894	4.35832	168.95841
5/7	2585261.38	2643914.24	2801530.67	7558120.50	2.26874	8.36547	192.35421
5/8	2611698.33	2670557.14	2829523.87	7599885.90	2.25366	8.34038	190.99402
6/7	88297.00	88576.11	89355.08	146752.36	0.31610	1.19833	66.20312
6/8	112145.03	112443.51	113967.05	213517.02	0.26616	1.62470	90.39365
7/8	4468.23	4456.87	4459.16	4614.43	-0.25420	-0.20289	3.27215

Table 15. Percent of change in resistance distance attributable to renewable energy development in renewable development scenarios for each desert tortoise critical habitat pair.

Habitat Pair	Percent (%) Change in Resistance Distance Value Attributable to Low Scenario	Percent (%) Change in Resistance Distance Value Attributable to High Scenario
1/2	33.63	96.30
1/3	1.79	89.27
1/4	-0.00	-0.03
1/5	66.17	98.98
1/6	51.47	92.59
1/7	74.56	93.67
1/8	74.63	93.69
2/3	0.06	0.06
2/4	64.11	89.59
2/5	65.10	89.61
2/6	51.06	85.51
2/7	75.95	89.14
2/8	75.99	89.18
3/4	4.80	62.27
3/5	5.80	64.64
3/6	34.44	83.60
3/7	58.50	85.80
3/8	58.64	85.89
4/5	59.17	99.88
4/6	44.44	96.08
4/7	71.04	96.41
4/8	71.15	96.42
5/6	44.59	96.32
5/7	71.26	96.63
5/8	71.37	96.64
6/7	73.39	99.21
6/8	83.40	99.44
7/8	-25.36	108.04

Comment [%1]:

Comment [%2R1]:

9.1.4.3 High Renewable Energy Development Scenario

As with the bighorn sheep analysis, a markedly greater increase in all resistance distances (excluding that between habitats 1 and 4) occurred between the Present and High Renewable Energy Development scenarios (see Table 14).

Calculation of the percent change between the resistance distances from these scenarios (see Table 15) revealed that the largest overall percent increase was a 447% increase in resistance distance between habitats 3 and 4. A greater than 100% increase was observed for numerous pairwise habitat connections including those between critical habitat 3 and all other habitats (except habitat 2),and those between critical habitat 6 and critical habitats 1, 3, 4, and 5. Furthermore, most of the observed change in the pairwise resistance distances between all critical habitats (excluding those between habitat 1 and 4 and 2 and 3) could be attributed to the renewable energy developments included in the scenario (see Table 15). More than 80% of the increase in resistance observed under this scenario was attributable to renewable energy developments.

The greatest effect of renewable energy development on the change in resistance was observed between critical habitats 4 and 5. Qualitative analysis of the connectivity map for this scenario illustrates that one of the renewable energy developments included in the High Scenario falls across the shared border and within both critical habitats, disrupting connectivity. A distinct decrease in the probability of movement (from yellow to red) between critical habitats 3 and 6 is also apparent in the connectivity map for this scenario, specifically where the high development creates a band of CREZs in between these two habitats. In fact, critical habitat 6 is surrounded by scattered renewable developments under this scenario and thus connectivity to and from this critical habitat is severely impacted. If such renewable developments are to be built, mitigation measures to facilitate tortoise movement should be included in their design. Further mitigation of the impact of renewable developments can be achieved through management strategies such as translocation of tortoise populations in critical habitat 6 or designation of new critical habitat areas to replace those directly impacted.

9.1.5 Areas of High Combined Connectivity for Both Species

Zonation was used to identify areas important for the maintenance of connectivity for both the bighorn sheep and desert tortoise under the High Renewable Energy Development scenario. The yellow areas in the map output (the Weighted Range Size Corrected Richness, or wrscr map, see Figure 22) are areas with high wrscr-values, which indicate high aggregate probability of movement for both the bighorn sheep and desert tortoise. These areas are concentrated in the southern and northern central part of the study region and are important for the maintenance of connectivity for both species under this scenario. Areas shown in light grey have lower wrscr-values and provide only moderate combined benefit to the connectivity of both species, while those in dark grey have the lowest wrscr-values and provide little combined benefit to the connectivity of both species. Renewable Energy

Developments included in the High Development Scenario are indicated in black.

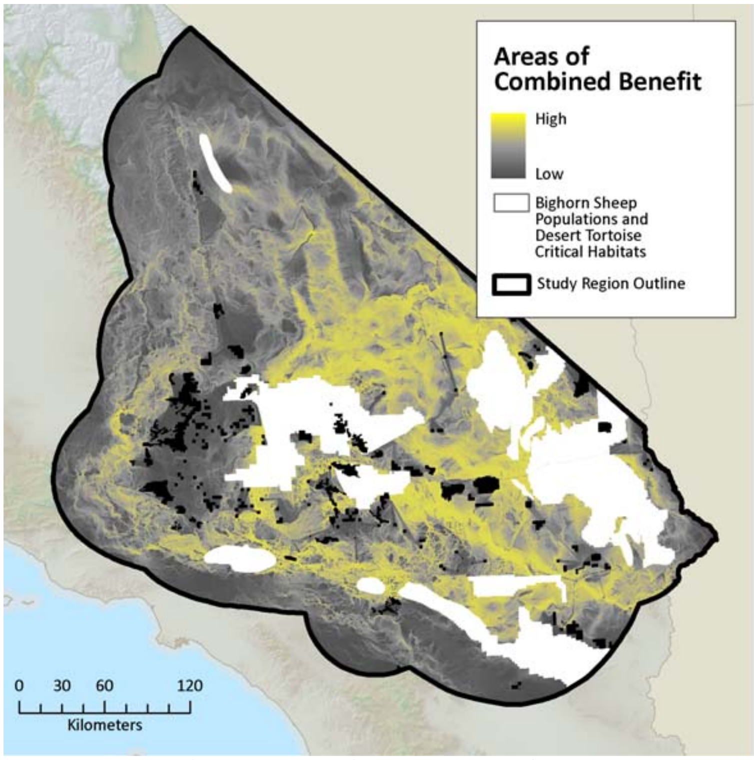


Figure 22. Areas of combined benefit to connectivity of both the bighorn sheep and desert tortoise under the High Renewable Development Scenario. Areas in white denote focal nodes used in the connectivity analysis, while green areas are those which are likely to contribute to the maintenance of connectivity for both bighorn sheep and desert tortoise.

Because areas of important movement for both bighorn sheep and desert tortoise occur in the center of the study area, areas of the highest combined benefit to the connectivity of both species were also largely concentrated in the center of the study region. The placement of development in this area (e.g. the band of renewable energy developments running in a northwest to southeast direction through the center of the region) forces species to move around them; thus, pathways on either side of the developments become more important to connectivity of both species.

Additional areas important to connectivity of both species occur in the area just to the northeast of the critical habitats and populations where almost no renewable projects are cited. Similarly, some pathways are highlighted in the western portion of the study region to the left of the large concentration of renewable energy developments located in that area. The far northern part of the study region has very few areas that benefit the connectivity of both species, likely due to the fact that the desert tortoise critical habitat areas and most of the sheep habitats analyzed are concentrated in the center of the study region and thus movement between those habitats and populations does not generally extend into the northern part of the study region.

The highlighted areas are important to the connectivity of both bighorn sheep and desert tortoise, supporting movement and gene flow of both species at once. As such, government landowners and conservation organization may consider prioritizing such areas to increase conservation efficiency.

10.0 Discussion

Renewable energy is absolutely critical to the success of this nation’s energy future. However, the development of large scale renewable energy projects can disrupt connectivity for species of concern such as the bighorn sheep and desert tortoise. While it is imperative that we achieve California’s renewable energy goals, renewable development must be completed in a sustainable manner in order to preserve the ecological integrity of the regions being developed, as well as the persistence of species in those areas. This analysis reveals a number of specific insights regarding the effects of renewable energy development on connectivity. Understanding such impacts can help inform siting decisions and mitigation strategies which can aid in reducing the ecological impacts of renewable development.

10.1 Effects of Large-scale Renewable Energy Development on the Bighorn Sheep and Desert Tortoise

The development of certain Competitive Renewable Energy Zones (CREZs) included in this analysis will impinge on highly suitable habitat for both the desert tortoise and bighorn sheep in the West Mojave. In addition to such direct impacts to habitat, however, the development of a vast network of projects throughout the region and the resulting obstruction to important movement pathways may have serious consequences for species movement and gene flow.

Impacts to connectivity arise even in the Low Renewable Energy Development scenario, although most of the development is to the west of the bighorn sheep populations and desert tortoise critical habitat areas. The siting of these projects can still have impacts on the metapopulation as a whole if, for example, suitable habitat areas needed for re-colonization are completely isolated or large source populations are disconnected from the metapopulation. To avoid these impacts, planners can consider decreasing the amount of large-scale renewable energy development planned for the area, focusing renewable development in other appropriate sites, or incorporating measures into project designs in order to specifically mitigate effects to connectivity (e.g. reduced fencing, movement corridors, translocation, etc.).

10.1.1 Protecting Highly Suitable Habitat for Bighorn Sheep

Renewable energy developments can severely impact areas of highly suitable habitat that could be important to the survival of the bighorn sheep metapopulation. One example is the Cache Peak population, which went extinct sometime after 1994 (Epps et al. 2003). However, because bighorn sheep exist as small local populations, re-colonization of previously used habitat patches during years of stable population growth is critical to persistence of the bighorn sheep metapopulation (Epps 2006). The analysis of resistance distances between all 69 bighorn sheep focal nodes indicated that sheep would have 5-50 times more difficulty moving to the Cache Peak area if all developments in the region were constructed. This increased difficulty in moving to Cache Peak from surrounding populations is due to the fact that (1) the Tehachapi CREZ is sited directly atop suitable habitat at Cache Peak; and (2) five other CREZs (Inyokern, Kramer, Fairmont, Victorville, and Barstow) stand between the Cache Peak and its closest neighboring populations (see Figure 23). Maintaining connectivity to potential re-colonization sites such as Cache Peak is important to maintaining the viability of the bighorn sheep populations in the West Mojave. Cache Peak serves as an example of how a network of projects, even when sited in areas where sheep do not currently exist, can affect metapopulation dynamics.

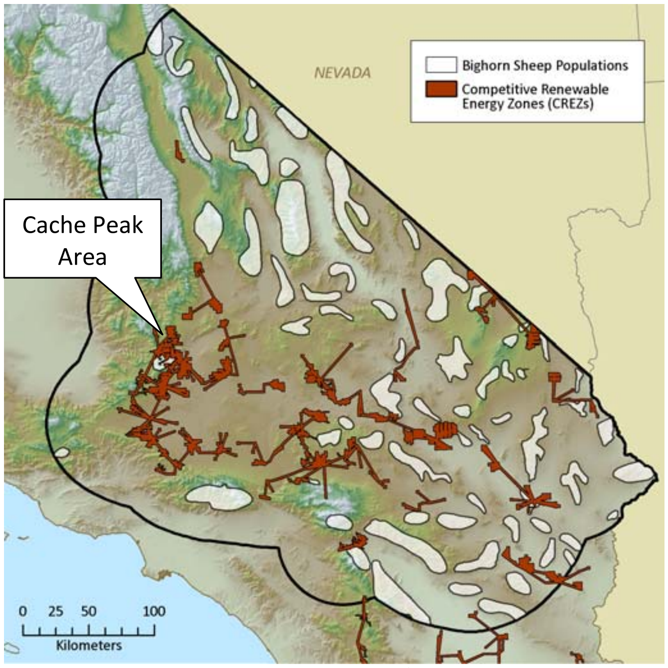


Figure 23. Impacts to connectivity to the Cache Peak area.

10.1.2 Protecting Important Bighorn Sheep Source Populations

Connectivity maps for bighorn sheep (see Figure 19) illustrate that many renewable energy developments are concentrated just north and east of the San Gabriel Mountain bighorn sheep population. This population consists of approximately 250-300 individuals – the most in the region – and is also the most vulnerable to genetic isolation according to calculations of expected changes to migration rates (see Table 13). Renewable energy developments surrounding the San Gabriel population eliminate many of the pathways connecting it to other populations to the north and west and redirect this movement to a pathway northwest of the population. This is not only a problem for the local San Gabriel Mountain population, but also for the overall metapopulation given that the San Gabriel population is an important source of migrants throughout the region. The implications of this isolation and redirection are two-fold. Either the development of renewable energy projects surrounding the San Gabriel population should be minimized to preserve some existing pathways, or, if the projects must all be developed, emphasis should be placed on preserving the pathway to the northwest of the San Gabriel population since it experiences an increased probability of movement.

It is important to note that changes to connectivity in the region arising from large-scale renewable energy development are in addition to impacts that are already likely to occur due to climate change. For example, as temperatures increase bighorn sheep will be confined to higher elevations, suitable habitat will be reduced, and some populations will become increasingly isolated. In order for populations less impacted by rising temperatures (e.g. San Gorgonio, Old Dad, and San Gabriel populations, see Figure 19) to serve as refugia and sources of migrants for a viable metapopulation, they must remain connected to other populations and to habitat suitable for re-colonization. Accordingly, care should be taken when siting projects to prevent the isolation of important source populations and potential areas of re-colonization.

10.1.3 Conserving Desert Tortoise Critical Habitat and Movement

In both the Low and High Renewable Energy Development Scenarios, a large portion of the renewable energy developments fall to the west of two desert tortoise critical habitats (habitats 2 and 6, see Figure 21). A large portion of the increase in resistance to movement between these habitats can be attributed to the renewable developments, providing additional support for minimizing the development of renewable energy projects in this region if possible. Alternatively, if such renewable developments are to be built, mitigation measures to facilitate tortoise movement (e.g. minimized road construction, minimized fencing, provisions for translocation) should be included in their design.

The development of several CREZs would also cause direct habitat loss in three desert tortoise critical habitats. The disturbances are located in the north of habitat 2, southern sides of habitat 3, and the northwest corner of habitat 6 (see Figure 21 and Appendices K and L). These direct impacts to critical habitat could be detrimental to the desert tortoise and should be avoided by prioritizing the development of other CREZs or by excluding specific development projects that fall within critical habitat areas.

10.2 Renewable Energy Development Planning Framework

California’s goals for renewable energy development, and the subsequent possible impacts to natural habitat in the West Mojave, are unprecedented. Developing renewable energy at this scale involves coordination at the federal, state, and local level among government jurisdictions, conservation organizations, and private landowners. Together, these groups can work to determine the most economic and environmentally sensible locations to site large-scale renewable energy in the West Mojave, and across the nation.

Planning efforts in the region include the Western Renewable Energy Zone (which encompasses the Western US and parts of Canada and Mexico), the federal Bureau of Land Management’s renewable energy Programmatic Environmental Impact Statement (PEIS) processes, California’s Renewable Energy Transmission Initiative, and California’s Renewable Energy Action Team, among others (see Section 6.2.3.2).

The Western Governor’s Association’s Renewable Energy Zone initiative is in the very initial stages, and will include both the identification of renewable energy zones as well as associated transmission planning. The federal Bureau of Land Management’s wind and geothermal PEIS processes are already complete and the scoping period for the Solar PEIS ended in July 2008; however, the PEIS planners have offered to incorporate additional public comments into the draft of the solar PEIS (available 2009) to the extent feasible. A recent memorandum to the BLM from the Secretary of the Interior prioritizes renewable energy development to hasten application processing (USDOI 2009), and has brought new attention to the BLM’s renewable energy planning efforts.

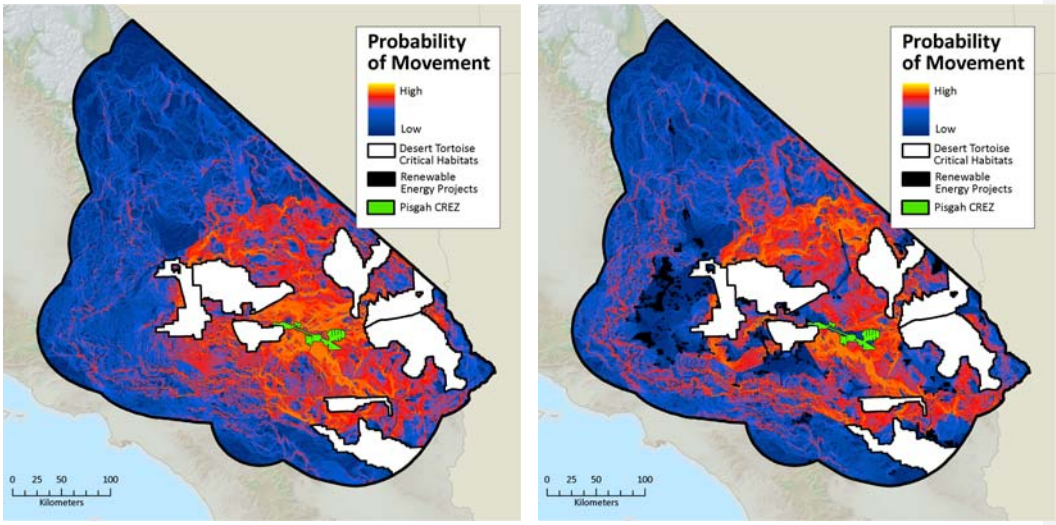
In its Phase 1B Final Report, RETI recognized the need to incorporate a more robust connectivity analysis (RETI Stakeholder Steering Committee 2009) into decision-making. RETI will continue its transmission-planning work in Phase 2 by expanding upon its previous analysis and incorporating inter-CREZ transmission lines. In order to improve upon the existing environmental analysis, the methodology and analyses from this project should be incorporated into the final Phase 2 Report as much as possible, given the short timeframe for doing so.

10.3 Disruption of Connectivity Due to the Pisgah CREZ

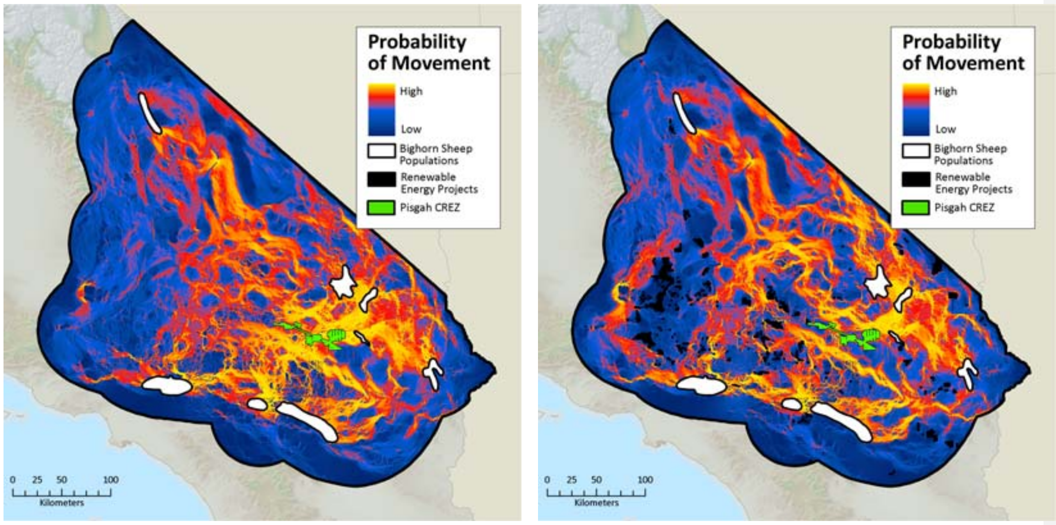
One specific development proposed for the center of the study region under the High Development scenario – the Pisgah CREZ – appears to have particularly detrimental impacts to specific pathways. The Pisgah CREZ is actually a composite of two sub-CREZs as defined in the RETI analysis (see Section 6.2.3.2): Pisgah-A and Pisgah-B. Pisgah A is composed exclusively of solar projects, while Pisgah-B contains both solar and wind projects. Because Pisgah-A is considered more economically viable than Pisgah B, The RETI Environmental Working Group chose to focus their environmental analysis on Pisgah-A and did not conduct an analysis of Pisgah B (RETI Stakeholder Steering Committee 2009). Our analysis shows that the projects in both Pisgah A and B lie in areas important to the connectivity of both the desert tortoise and bighorn sheep (see Figure 24).

The Pisgah CREZ lies squarely in the center of the eight desert tortoise critical habitats within the study region and in the center of an important northeast-to-southwest movement pathway between a number of the bighorn sheep populations analyzed. For both species the placement of the Pisgah CREZ results in connectivity being shifted large distances (on the order of >50 km) around the development. Such diversion highlights new areas of increased movement probability which may become even more critical as climate change and other forms of development continue to impact the area. Conservation of these highlighted areas would likely be critical to the survival of these species if the Pisgah CREZ is developed.

For bighorn sheep, the Pisgah CREZ's disrupts a major movement pathway connecting populations in the southwest to those in the northeast, causing serious impacts to specific sheep populations. As such, the Pisgah CREZ contributes to the physical and genetic isolation of the Little San Bernardino population. As one of the largest populations in the region with 150-200 individuals, this population is an important component of the bighorn sheep metapopulation. With the development of the Pisgah CREZ and other renewable energy developments running northwest to southeast in the High Renewable Energy development scenario, this population becomes significantly more isolated from the four populations in the northeast severely impacting the movement of individuals and gene flow across the study region (see Figure 24).



a. Desert Tortoise Present Scenario **b. Desert Tortoise High Scenario**



c. Bighorn Sheep Present **d. Bighorn Sheep High Scenario**

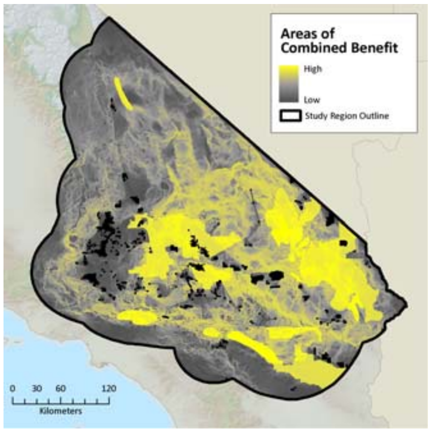
Figure 24. The impact of the Pisgah CREZ on important connectivity areas for desert tortoise (c and d) and bighorn sheep (a and b) is evident in a comparison of the present and high renewable energy development scenarios. Pisgah is labeled in green, high connectivity areas are indicated in yellow.

Fortunately, RETI estimates the Pisgah development timeframe to be “mid-long” which should allow development planners and conservation organizations the time needed to study its potential ecological impacts in greater detail. Given the placement and potential effects of the projects within the Pisgah CREZ to desert tortoise and bighorn sheep movement, RETI should consider reevaluating the environmental score of Pisgah-A used in its original analysis to better reflect impacts to connectivity. Should the Pisgah-B sub-CREZ be considered further for development, it will be critical to include connectivity analyses such as this one in the environmental assessment.

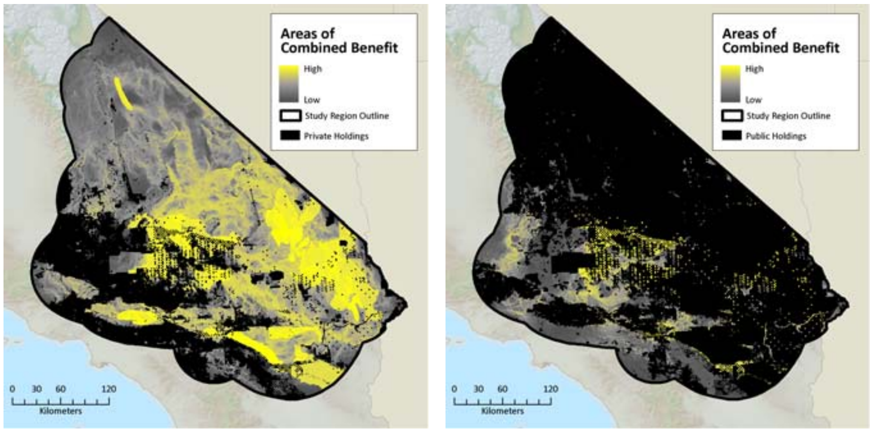
10.4 Conserving Connectivity on Public and Private Lands

Our research group identified areas likely to contribute to the maintenance of connectivity for both the bighorn sheep and desert tortoise (see Figure 22). Because the majority of land in the West Mojave is owned and managed by federal and state agencies, it is not surprising that most of the areas important to connectivity of both bighorn sheep and desert tortoise fall within public holdings (see Figure 25a and 25b). Most of the large-scale renewable energy development proposed for the West Mojave has been proposed for public lands with lesser degrees of protection (e.g. BLM holdings); thus, public land use decisions will become increasingly important to the maintenance of connectivity in the region. Public holdings that encompass areas important to combined connectivity may thus be important and efficient targets for groups hoping to influence public land management choices to benefit connectivity.

Some areas of important connectivity lie on private land (see Figure 25a and 25c). Although conservation organizations own and manage much smaller quantities of land in the West Mojave, their holdings comprise an important complement to existing protected areas. Private lands that have been identified as important to connectivity may thus be efficient targets for groups hoping to acquire land or facilitate conservation easements in order to control land use and protect connectivity and ecological integrity in the West Mojave. Although some of the private land identified in Figure 25b is urbanized and thus not likely appropriate for conservation, certain areas north of Los Angeles encompass land that is identified as important to connectivity for both bighorn sheep and desert tortoise. Conservation organizations may consider focusing on two areas that are largely undeveloped and especially necessary to connectivity: 1) the area west of Palmdale and Lancaster, east of Victorville, and south of Edwards Air Force Base and 2) the area east of Bakersfield, west of Tehachapi, and north of Frazier Park.



(a) Areas of Combined Benefit



(b) Areas of Combined Connectivity on Public Lands

(c) Areas of Combined Connectivity on Private Lands

Figure 25. (a) Areas important to connectivity of both bighorn sheep and desert tortoise; (b) public and (c) private holdings in the West Mojave study region. Areas in yellow are those which are likely to contribute to the maintenance of connectivity for both bighorn sheep and desert tortoise in the high renewable energy development scenario. In (b) private lands are blocked out, showing areas of high combined connectivity on public lands. In (c) public lands are blacked out, showing areas of high combined connectivity on private lands.

11.0 Recommendations

In the West Mojave, vast expanses of land are owned and managed by federal and state governments. An effective balance between the economic and energy needs of the state and environmental integrity of the region will likely rely on sound renewable energy development planning. While some land-use planning processes are well underway, others are just beginning, and the information and recommendations provided in this report may be a timely addition to their work.

Non-government conservation organizations serve other functions. They may act as private and public sector watchdogs, constituent representatives, special interest advocates, and as sources of information for environmental policy. Importantly, conservation organizations also work to preserve ecology through land acquisition and the facilitation of easements on other private land. Though their influence is much smaller in scope than that of government agencies, the land managed by conservation organizations forms an important compliment to federal and state holdings.

Recognizing the difference in goals, reach, and approaches used by these two groups, this project divides recommendations to specifically target each group (Sections 11.1 and 11.2). Recommendations concerning additional avenues for future research are also included (see Section 11.3).

11.1 Recommendations for the Renewable Energy Development Process

Based on our analyses of desert tortoise and bighorn sheep connectivity in the West Mojave, our research group recommends that renewable energy planners and developers:

1. *Consider reevaluating the environmental impact of the sub-CREZs and projects contained in the Pisgah CREZ.* Because of the multiple impacts of the Pisgah CREZ to desert tortoise movement and sheep movement and gene flow, the RETI process may consider reevaluating the environmental score of Pisgah-A and its associated projects. Should Pisgah-B become more economically viable, RETI should definitely include a more detailed connectivity analysis than was included in the other CREZ analyses (see Section 6.2.3.2).

2. *Refrain from developing all of the large-scale renewable energy projects surrounding the San Gabriel population*. The San Gabriel population is an important source of migrants for the rest of the metapopulation. In the face of climate change, the population may also serve as an important genetic refugia. This is an important consideration for future development too (that is, if there is a metapopulation of concern, conduct connectivity analyses specifically with that metapopulation to make sure its important source populations are not getting cut off).

3. *Consider relocating or reconsidering projects that fall within designated critical habitat areas or highly suitable sheep habitat.* Specifically, consider relocating or not developing those projects that limit connectivity between desert tortoise critical habitat, and consider limiting the amount of development surrounding the Cache Peak area in the west, which could serve as an important location for bighorn sheep recolonization.

4. *Incorporate connectivity analyses more specifically into regional and local planning processes.* Because this network of large-scale projects will span across a vast area, analyzing the cumulative impacts that renewable energy development might have on ecological processes− such as connectivity− over long time horizons is an important consideration. Incorporating an analysis such as the one developed by this project can help inform decision-makers about which locations are ideal to develop or to conserve.

   A more detailed discussion of the specific planning processes is available in Section 6.2.3.2. Specifically, the following stages of the planning processes in the West and in California are ideal arenas for integrating connectivity analyses:

   - Western Renewable Energy Zones Initiative Phase 1 identification of Renewable energy zones and Phase 2 identification of transmission corridors;

   - BLM Programmatic Environmental Impact Statements (PEISs), creation of Best Management Practices associated with the PEISs, and project application processing. As one of the major landholders and managers in the West Mojave region, we also recommend that the BLM work with other natural resource agencies such as the National Park Service to maintain connectivity between and among existing protected areas important for ecological persistence.

- Renewable Energy Transmission Initiative (RETI) Phase 2 transmission analysis. Incorporating connectivity analyses into the RETI process is specifically important given that it is likely to provide a foundation for identifying renewable energy zones for the Desert Renewable Energy Conservation Plan and will also inform the Western Renewable Energy Zone planning process; and

- Renewable Energy Action Team (REAT) Desert Renewable Energy Conservation Plan and Best Management Practices for renewable energy development.

11.2 Recommendations for Conservation Organizations

Conservation organizations that may be interested in this project include, but are not limited to The Nature Conservancy, Natural Resources Defense Council, Desert Managers Group, Mojave Desert Land Trust, Desert Tortoise Council, and Bighorn Institute.

Based on our results, our research group recommends that organizations such as these:

1. *Promote good land use practices on public lands to ensure conservation of connectivity.* Our research group identified areas likely to contribute to the maintenance of connectivity for both the bighorn sheep and desert tortoise (see Figure 22); most of these areas lie within lands held by federal, state, or other public agencies (see Figure 25). Conservation organizations can help protect connectivity in these areas by advocating for land use practices which minimize impacts to connectivity.

2. *Prioritize existing land holdings encompassing high levels of constricted connectivity.* The landholdings of conservation organizations provide an important complement to federal and state protected areas, and protecting connectivity on these lands is equally important.

3. *Consider purchasing additional private land to conserve connectivity*. A substantial portion of the West Mojave is privately owned (see Figure 25). The areas important to future connectivity that can be acquired are visible underneath the layer of publicly-held lands. These areas can be efficient targets for land acquisitions, conservation easements, or other conservation efforts (Sutherland 2004). Acquiring local assessors data will be helpful in determining specific land ownership and value in these particular areas.”

4. *Provide expertise for similar analyses and expand upon our research*. By incorporating other species of concern or flagship species, more areas important to connectivity could be highlighted. More specific suggestions for directions that future research might take can be found below (Section 11.3). Specifically, conservation organizations have the ability to provide important feedback to the Renewable Energy Action Team (REAT) and Desert Renewable Energy Conservation Plan, as well as to the Renewable Energy Transmission Initiative, to provide expertise and experience on ecology-related issues such as connectivity. These organizations could work to monitor and participate in REAT's land designations and provide feedback to RETI's siting decisions to ensure that areas of critical connectivity are conserved.

5. *Focus particular attention on potentially problematic large-scale renewable energy development that could interfere with high traffic connectivity areas.* The sub-CREZ Pisgah-B is a prime example. Conservation organizations should monitor any economic re-analysis of Pisgah-B so that they can act if Pisgah-B is found be economically competitive.

6. *Create a database of previously disturbed lands.* Most planning organizations, including RETI, recognize the value of siting renewable energy development on previously disturbed lands, instead of pristine lands, in order to minimize ecological impacts (RETI Stakeholder Steering Committee 2009). However, data on what land has been previously disturbed is largely unavailable. By creating this database, planning could be much more effective.

7. *Inform and support local communities during the planning process.* Much of the final planning stages are done at the local, community level (Sutherland 2004). Informing communities of both the need for renewable energy development as well as the need for conservation of ecological processes such as connectivity can help the public become more informed participants during the public feedback periods for these planning processes.

11.3 Future Directions for Research

As with any study, we recognize there are limitations to our analysis. We have identified the following opportunities to improve the current research, and to expand the scope of this analysis. Future research should:

1. *Evaluate additional species.* Our methodology can and should be replicated with other species to help create a more complete picture of the cumulative impacts of large-scale renewable energy development in the West Mojave. For example, a connectivity analysis for one or more plant species would complement the existing research by providing insights into the connectivity needs for plants and their respective pollinator species.

2. *Consider other energy development scenarios*. Our study considered only two of an almost infinite possible combination of renewable energy development scenarios. As described above, project siting is of critical importance in preserving connectivity throughout the West Mojave. Many of the concerns discussed above stem from the specific choice of developments used in the Low and High development scenarios. Had the number or combination of CREZs in each scenario differed, the impacts to connectivity would also differ. As it becomes more clear which projects are most likely to get built, this analysis could be recreated to provide a more realistic picture of the impacts of such development.

3. *Vary the conductive values of different energy types*. Our connectivity and gene flow analyses assumed all renewable energy development is completely impermeable to species movement. In fact, varying large-scale renewable energy technologies are likely to differ in permeability for different species. Recreating this analysis with a more accurate depiction of specific projects (e.g. fenced vs. unfenced) will yield a more accurate depiction of species movement and gene flow throughout the region.

4. *Study specific developments in more detail*. Future analyses should expand upon the more general conclusions made by this research by examining connectivity in more detail in areas where specific developments are found to be of particular concern. The Pisgah-B sub-CREZ area is a prime example (see Section 11.1). Recreating this analysis with and without projects of concern could provide insight into the specific impacts of that project to habitat quality, species movement, and gene flow.

5. *Recreate the analysis using more robust climate, vegetation, and urban modeling.* Although future (2050) temperature and vegetation models exist, they are generally available only at resolutions too coarse (1 km vs. 300m) to be applied to our connectivity and gene flow modeling. As a result, our analysis incorporated a simple climate model. In addition, given the lack of high resolution climate modeling to predict changes in vegetation, we assumed no real change in vegetation for our future scenarios. Finally, our analysis did not include key elements of planned development such as future roads, inter-CREZ transmission lines, long-

distance transmission lines, a proposed Inland Port in Antelope Valley, and planned rail projects. Future analyses should incorporate more detailed climate, vegetation, and urban development data to improve the predictive ability of the model. Future studies could also examine the sensitivity of the model to varying climate change and urban development scenarios.

6. *Reconstruct the analysis with larger desert bighorn sheep and desert tortoise data sets.* Although the models developed by this project are legitimized through model testing (see Section 8.3.5.1.3) results could be refined by using larger sets of data. For the Desert Tortoise, future connectivity modeling could employ focal nodes that correspond to recently defined genetically distinct tortoise populations (Murphy *et al*. 2007, Hagerty 2008). This would allow the desert tortoise connectivity model to be verified with genetic data and allow a desert tortoise gene flow analysis.

7. *Conduct on-the-ground research to confirm these result*s. Although this analysis uses proven methods to model habitat fragmentation, species movement, and gene flow, field studies that confirm these results could provide additional proof of the importance of specific areas to species movement. For example on-the-ground studies could confirm whether or not bighorn sheep use the corridors identified by this research.

8. *Perform population viability analyses given different development and climate change scenarios*. Population viability analyses could provide a complement to the existing genetic analysis to help predict which species, if any, will become extinct given the various scenarios.

9. *Re-evaluate the low development scenario.* Due to limited time and the format of the RETI GIS data, we were only able to model CREZs in their entirety. Thus, instead of modeling the specific sub-CREZs (Imperial North-A, Victorville-A) identified in the low development scenario, the entire CREZ (Imperial North A and B, Victorville A, B, and C) was modeled. Note that this does not affect the results of our high-development scenario as, in this scenario, every CREZ was fully developed and modeled.

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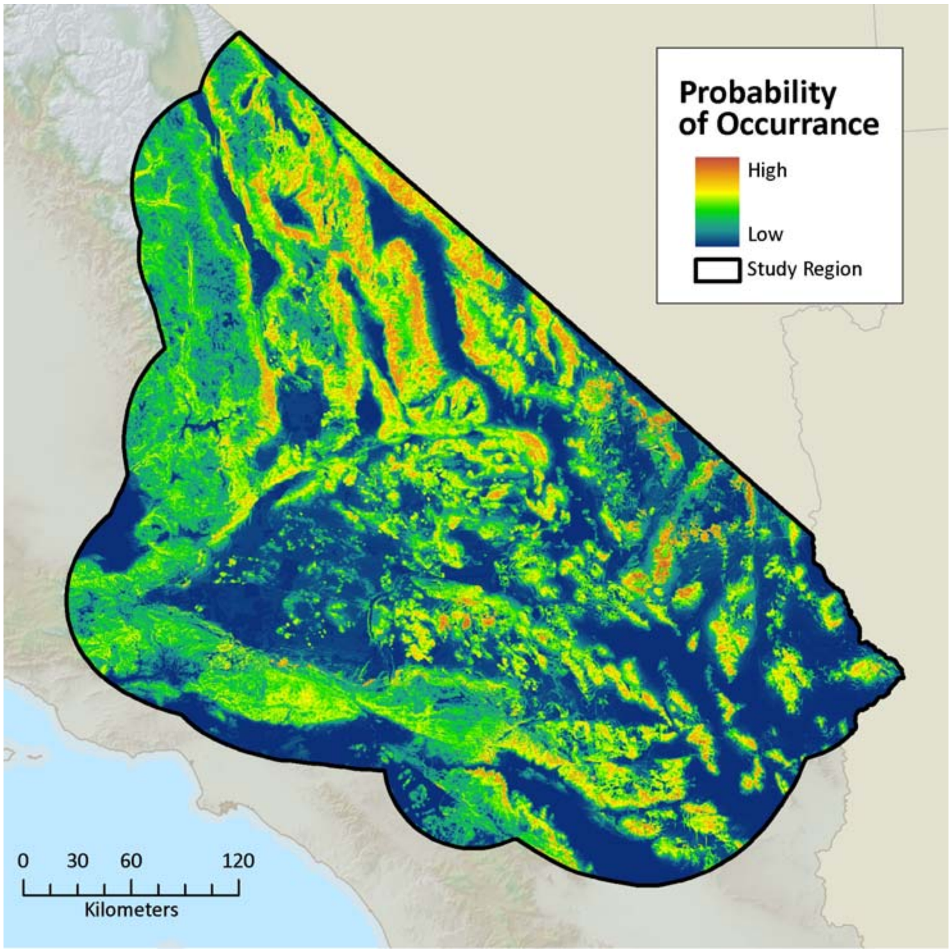
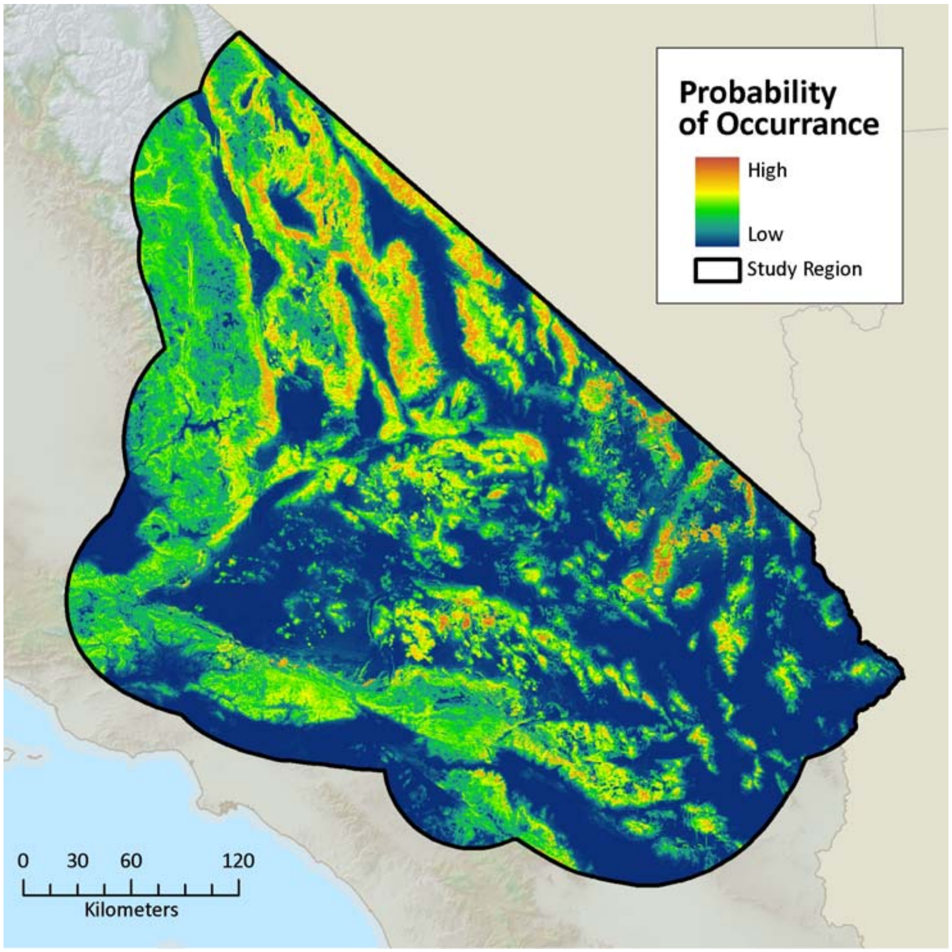
Appendix A. Desert Bighorn Present Sheep Probability of Occurrence

Desert bighorn sheep probability of occurrence for present as modeled by MaxEnt.



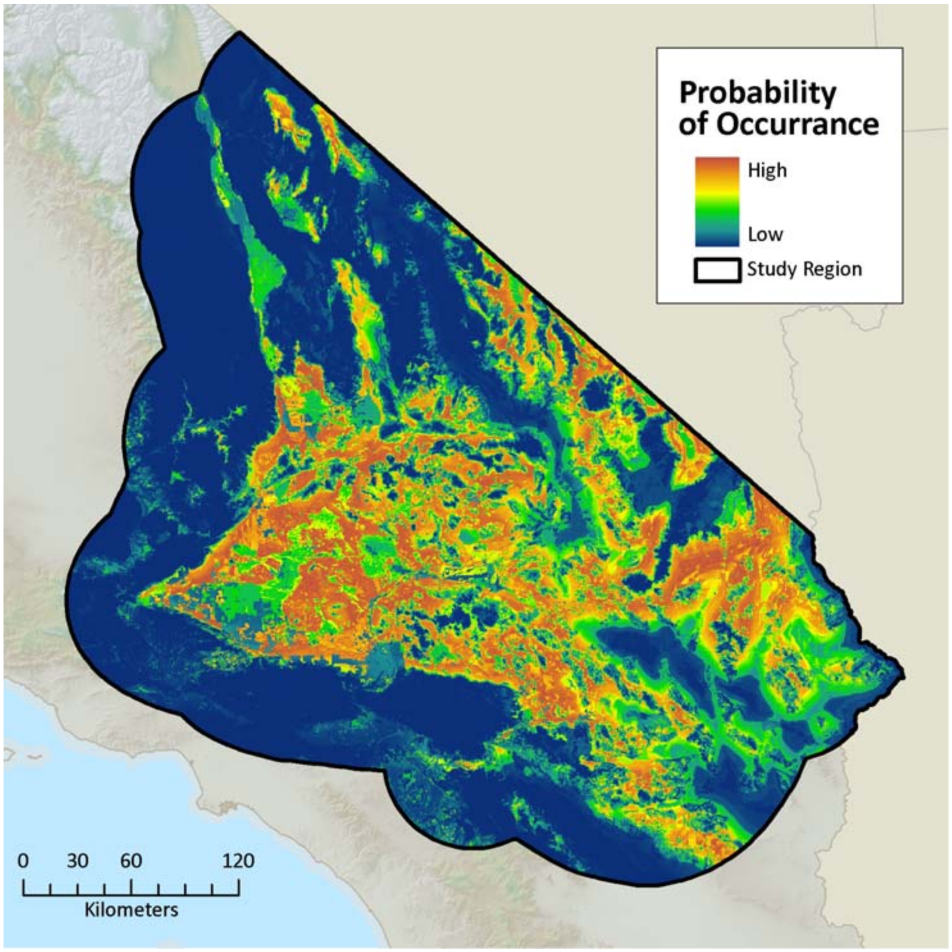
Appendix B. Desert Bighorn Future Sheep Probability of Occurrence

Desert bighorn sheep probability of occurrence for the future (2050) as modeled by MaxEnt. The model assumes a 2 °C increase in temperature due to climate change.



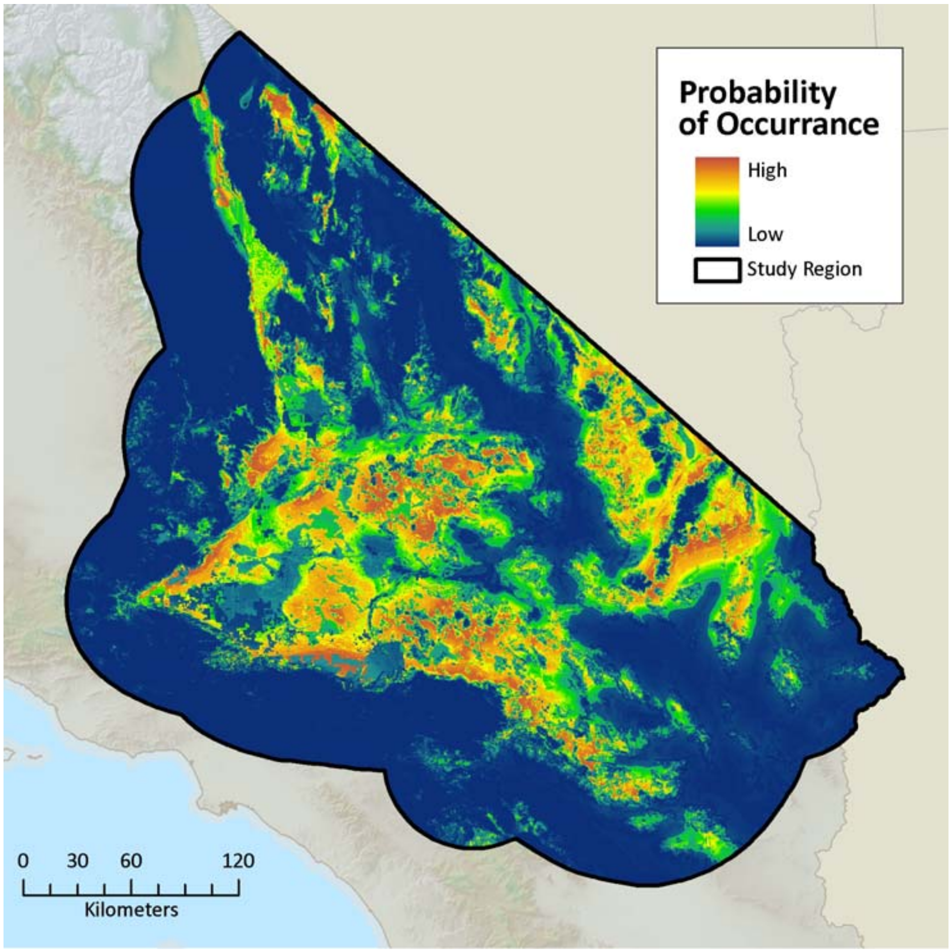
Appendix C. Desert Tortoise Present Sheep Probability of Occurrence

Desert tortoise probability of occurrence for present as modeled by MaxEnt.

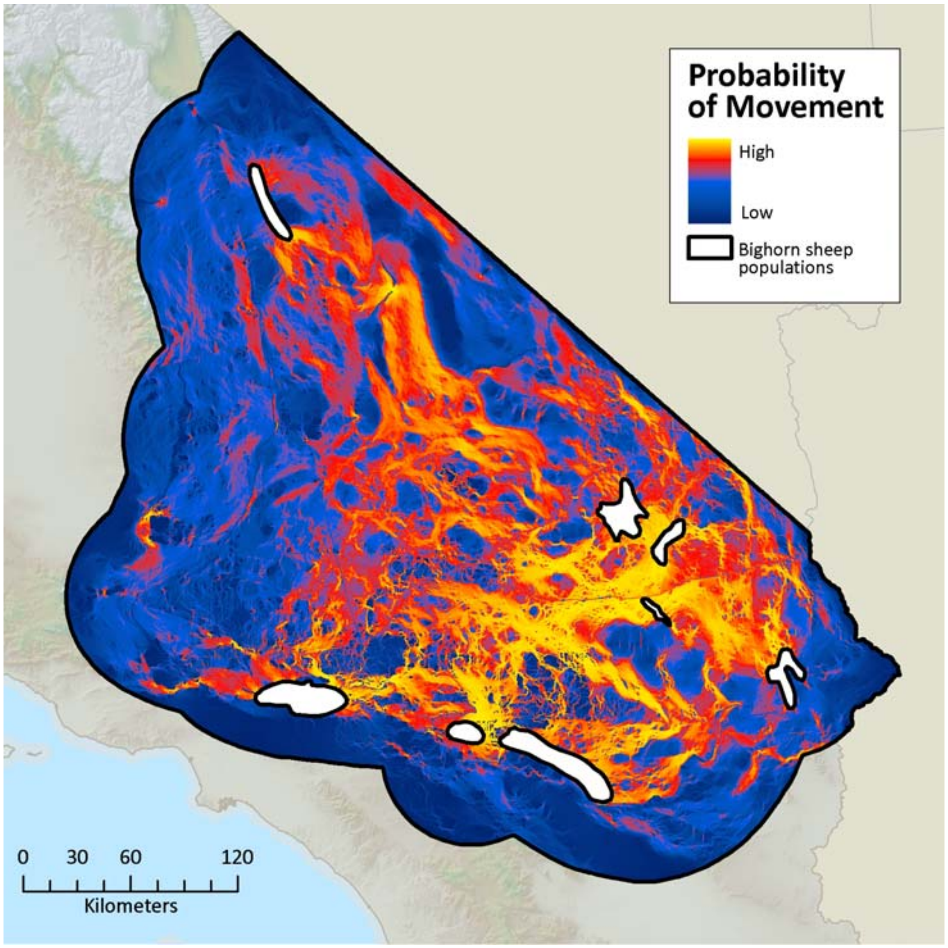


Appendix D. Desert Tortoise Future Sheep Probability of Occurrence

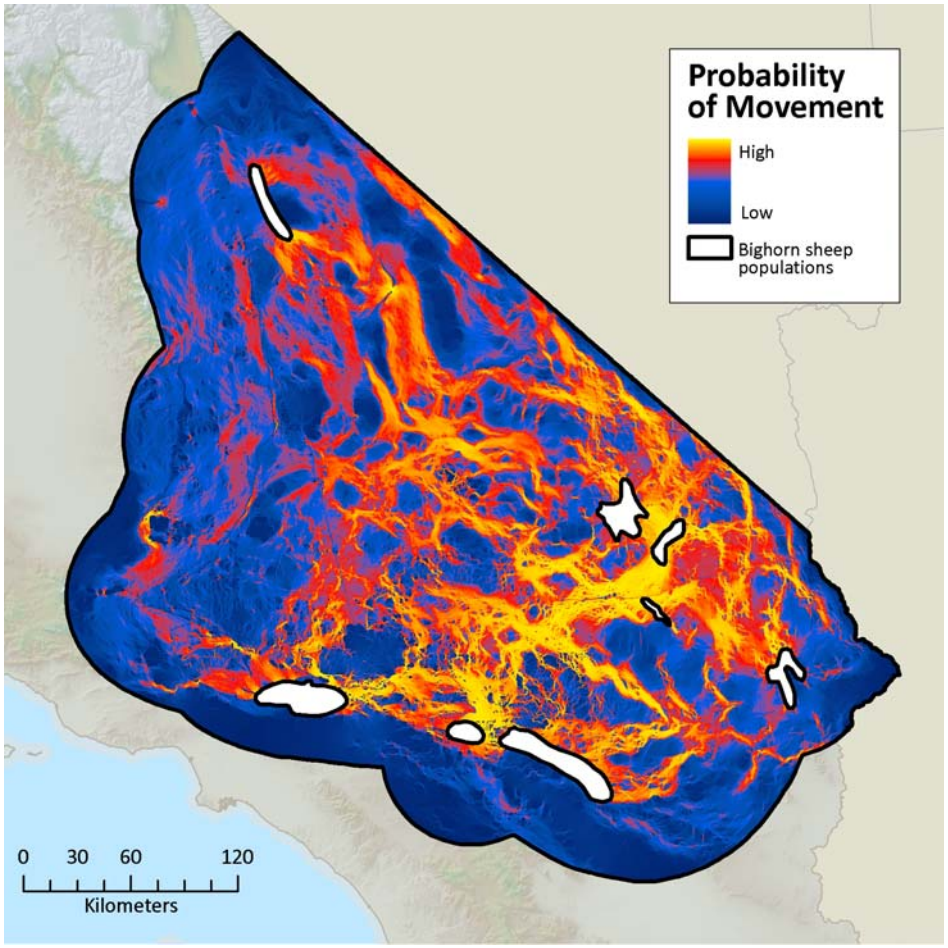
Desert tortoise probability of occurrence for the future (2050) as modeled by MaxEnt. The future assumes a 2 °C increase in temperature due to climate change.



Appendix E. Desert Bighorn Sheep Connectivity Map (Present)
Present connectivity for bighorn sheep as modeled by Circuitscape.

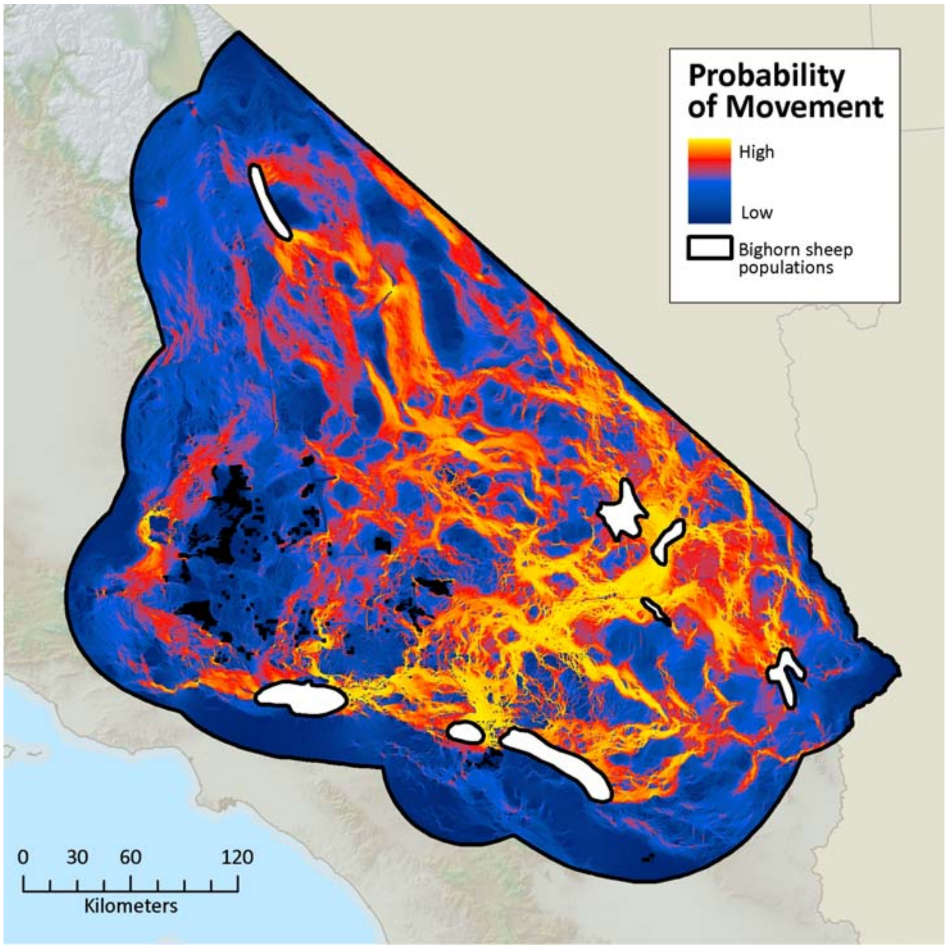


Appendix F. Desert Bighorn Sheep Connectivity Map (Future Baseline)
Future baseline connectivity (incorporating climate change) for bighorn sheep as modeled by Circuitscape.



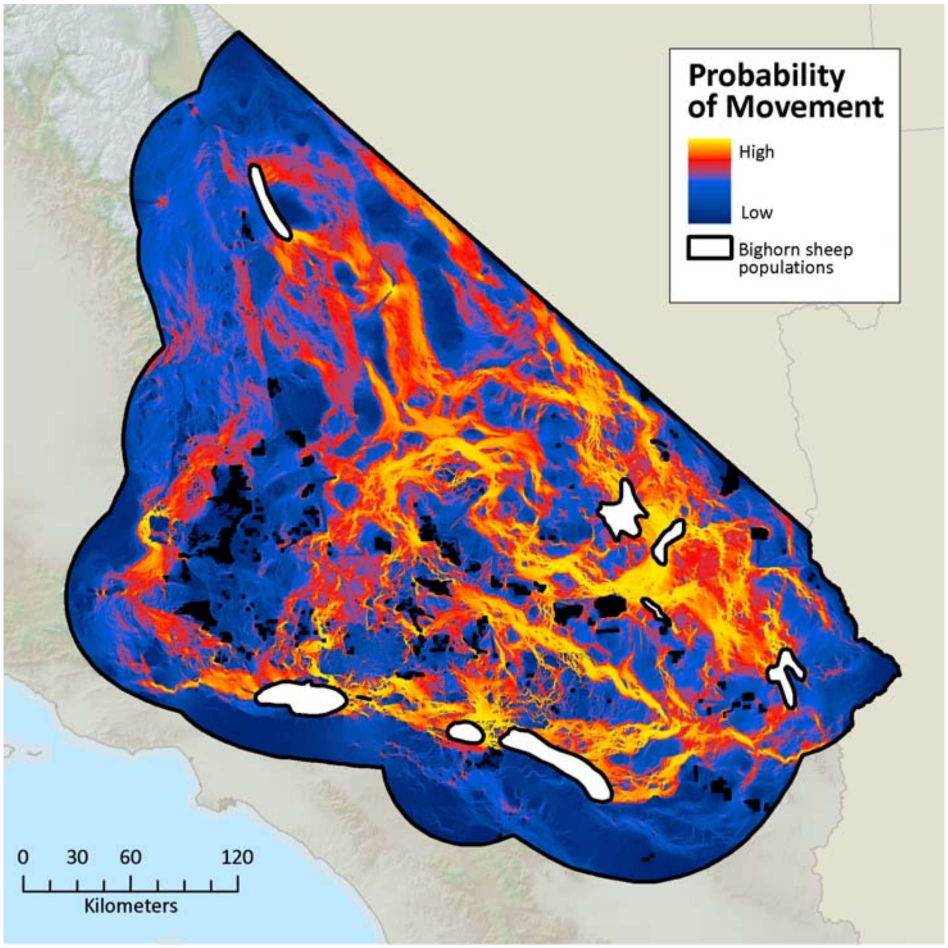
Appendix G. Desert Bighorn Sheep Connectivity Map (Future Low Renewable Energy Development Scenario)

Bighorn sheep connectivity in the future as modeled by Circuitscape, given climate change and low levels of large-scale renewable energy development. Energy projects are assumed to be impermeable and are shown in black.



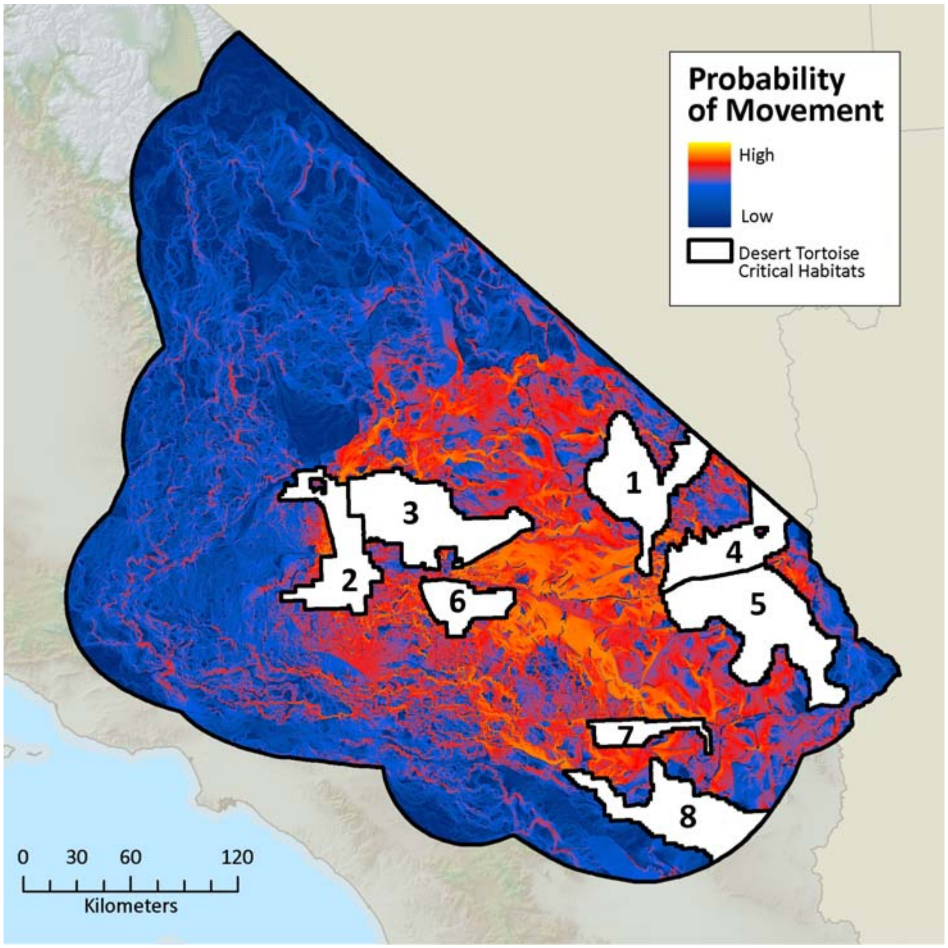
Appendix H. Desert Bighorn Sheep Connectivity Map
(Future High Renewable Energy Development Scenario)

Bighorn sheep connectivity in the future as modeled by Circuitscape, given climate change and high levels of large-scale renewable energy development. Energy projects are assumed to be impermeable and are shown in black.



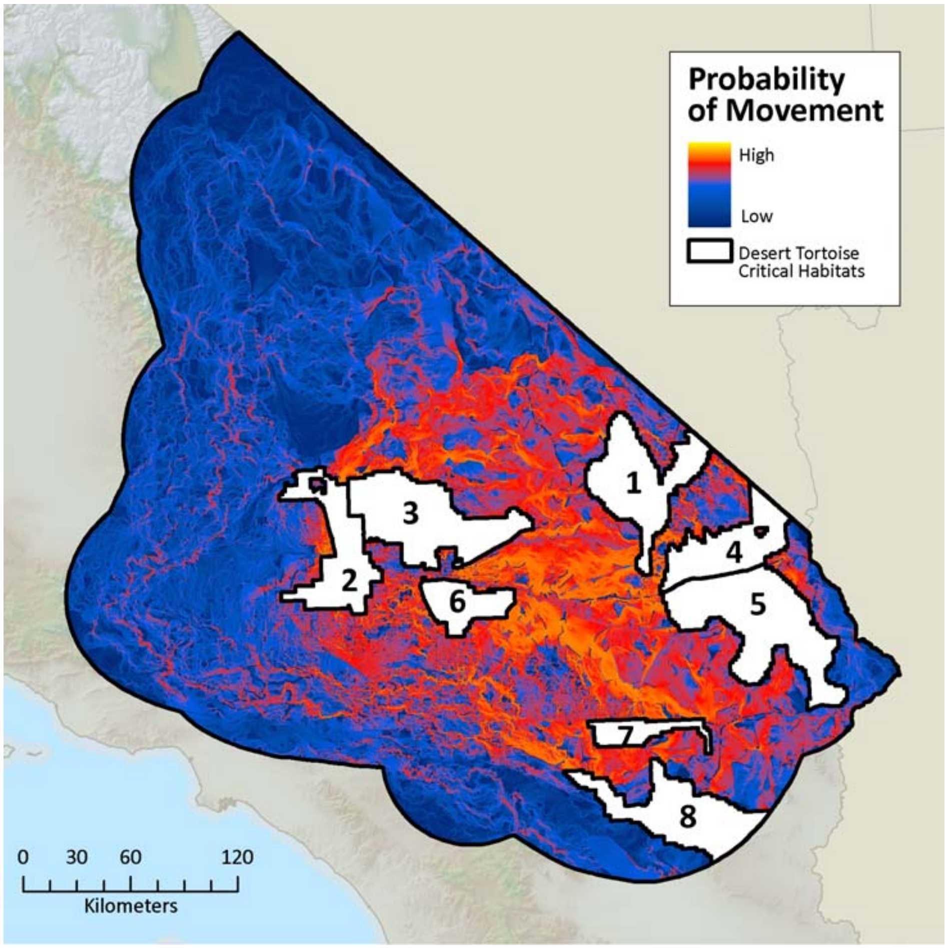
Appendix I. Desert Tortoise Connectivity Map (Present)

Present connectivity for desert tortoise as modeled by Circuitscape.



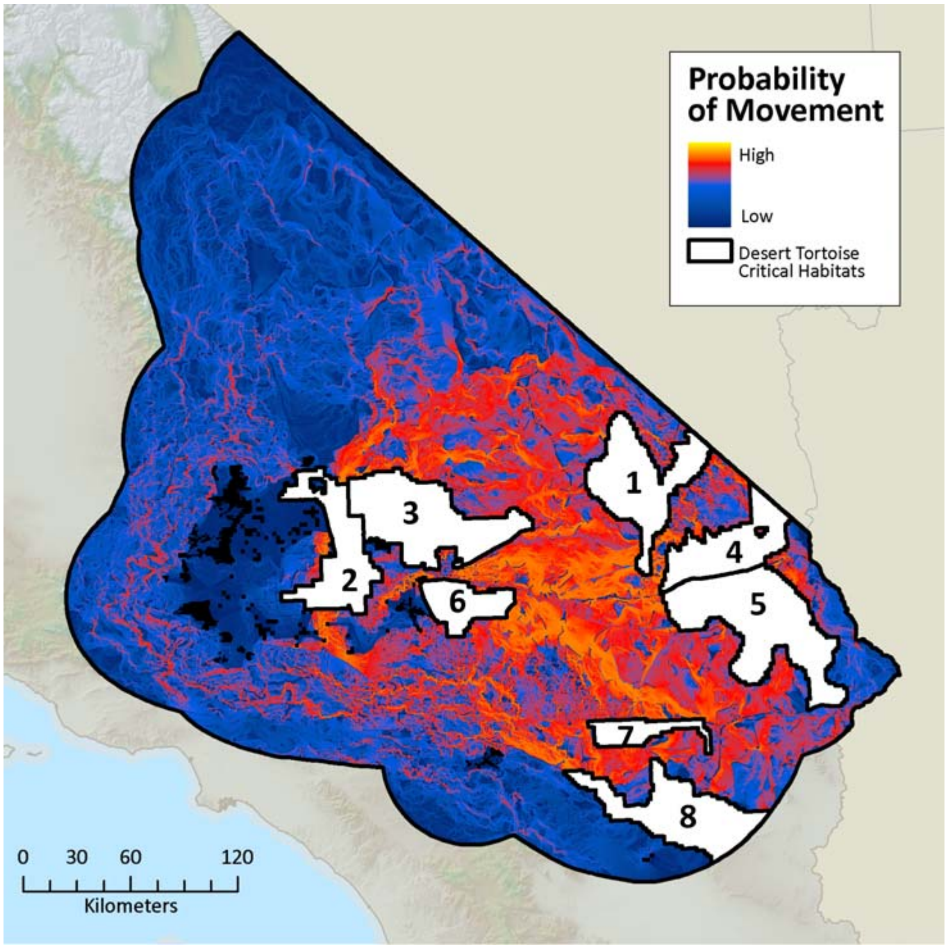
Appendix J. Desert Tortoise Connectivity Map (Future Baseline)

Future baseline connectivity (incorporating climate change) for desert tortoise as modeled by Circuitscape.



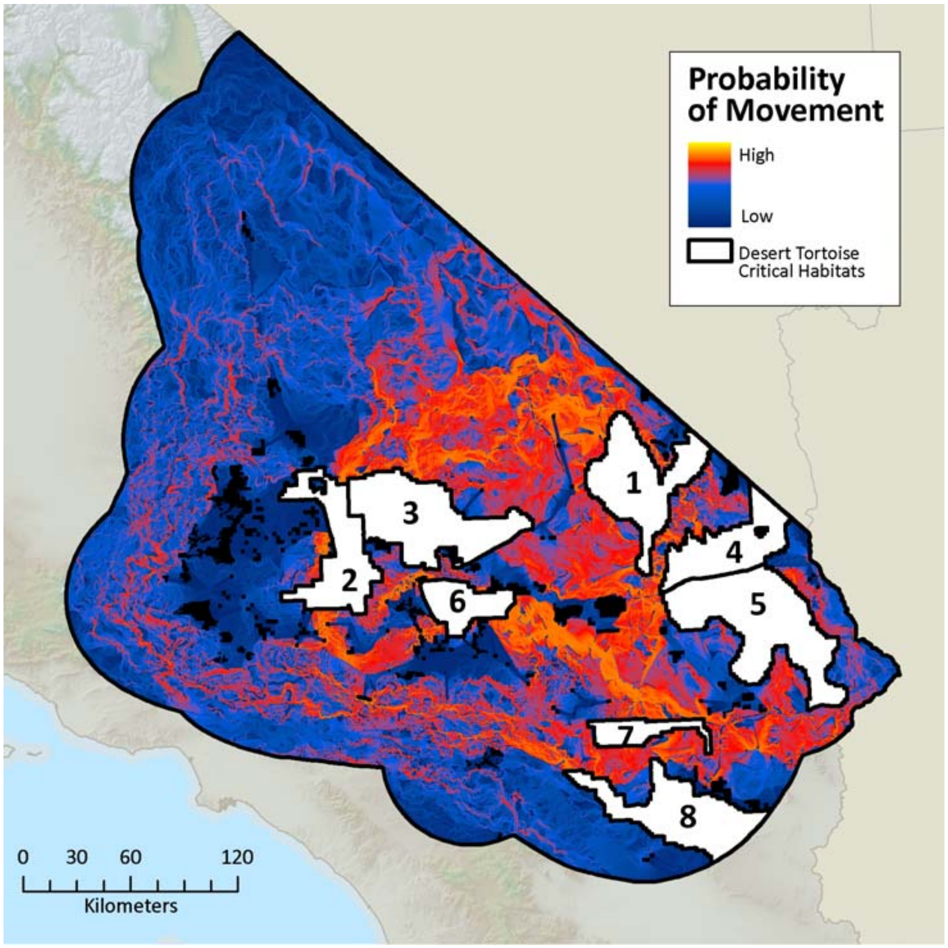
Appendix K. Desert Tortoise Connectivity Map (Future Low Renewable Energy Development Scenario)

Desert tortoise connectivity in the future as modeled by Circuitscape, given climate change and low levels of large-scale renewable energy development. Energy projects are assumed to be impermeable and are shown in black.



Appendix L. Desert Tortoise Connectivity Map
(Future High Renewable Energy Development Scenario)

Desert tortoise connectivity in the future as modeled by Circuitscape, given climate change and high levels of large-scale renewable energy development. Energy projects are assumed to be impermeable and are shown in black.



Appendix M. Desert Bighorn Sheep Resistance Distances Across All 69 Populations (Present)

	Coso Mtns	South White Mtns	Deep springs Range	Dry Mtn/Last Chance Range	Grapevine Mtns	Inyo Mtns	Tin Mtn	Funeral Mtn	Panamint Butte/ Hunter Mtn	South Panamint Mtns	Black Mtns	Nopah Mtns	Argus Range	Slate Range	Quail Range	Owlshead Mtns	Avawatz Mtns	Kingston/ Mesquite Mtns	Clark Mtns	Unnamed 1	Eagle Crags	San Rafeal Peak	Cache Peak	San Gabriel Mtns	Soda Mtns	Cady Mtns	Newberry Mtns	Ord Mtns	North Bristol Mtns	Old Dad Peak/ Kelso Mtns	New York Mtns	Castle Peak	Piute Range	Hackberry Mtns	Woods Mtns	Providence Mtns	Granite Mtns
Coso Mtns	0.0																																				
South White Mtns	-1.0	0.0																																			
Deep springs Range	12.1	-1.0	0.0																																		
Dry Mtn/Last Chance Range	10.2	-1.0	2.5	0.0																																	
Grapevine Mtns	26.1	-1.0	17.4	14.3	0.0																																
Inyo Mtns	9.7	-1.0	3.1	1.4	18.1	0.0																															
Tin Mtn	9.9	-1.0	4.1	0.6	17.7	1.7	0.0																														
Funeral Mtn	21.6	-1.0	20.6	18.1	28.7	18.7	17.8	0.0																													
Panamint Butte/ Hunter Mtn	9.2	-1.0	4.3	1.2	18.3	1.3	0.5	18.1	0.0																												
South Panamint Mtns	5.2	-1.0	12.7	10.6	26.3	10.2	10.2	19.5	9.4	0.0																											
Black Mtns	22.7	-1.0	27.7	25.5	39.7	25.4	25.2	4.3	24.8	17.9	0.0																										
Nopah Mtns	23.2	-1.0	29.9	27.8	43.0	27.6	27.5	29.6	26.9	17.8	20.6	0.0																									
Argus Range	1.4	-1.0	12.1	10.1	26.0	9.6	9.8	21.0	9.1	3.9	21.6	22.1	0.0																								
Slate Range	7.5	-1.0	15.2	13.1	28.7	12.7	12.8	20.8	12.1	1.6	18.1	17.3	6.3	0.0																							
Quail Range	8.1	-1.0	15.5	13.5	29.1	13.1	13.2	20.7	12.5	1.9	17.4	16.3	6.8	1.0	0.0																						
Owlshead Mtns	8.7	-1.0	16.0	14.0	29.6	13.6	13.7	20.9	13.0	2.3	17.2	16.4	7.5	2.2	0.8	0.0																					
Avawatz Mtns	10.8	-1.0	18.1	16.1	31.6	15.8	15.8	22.6	15.1	5.0	18.4	15.9	9.6	4.2	2.9	3.1	0.0																				
Kingston/ Mesquite Mtns	21.1	-1.0	27.9	25.8	41.1	25.5	25.5	28.5	24.9	15.6	20.3	3.0	19.9	15.1	14.1	14.2	13.5	0.0																			
Clark Mtns	25.5	-1.0	32.3	30.3	45.6	30.0	30.0	33.3	29.4	20.1	25.4	9.7	24.3	19.5	18.5	18.7	18.0	1.2	0.0																		
Unnamed 1	8.8	-1.0	16.2	14.1	29.7	13.8	13.8	21.2	13.2	2.8	17.6	16.0	7.5	1.9	0.4	1.5	1.9	13.7	18.2	0.0																	
Eagle Crags	8.7	-1.0	16.2	14.2	29.8	13.8	13.9	21.5	13.2	3.2	18.4	17.0	7.5	1.8	1.4	2.5	3.7	14.7	19.1	1.3	0.0																
San Rafeal Peak	83.4	-1.0	88.7	87.2	102.8	86.8	87.1	97.3	86.6	81.9	96.6	95.3	82.9	81.8	81.9	82.6	83.8	92.9	97.1	82.1	81.6	0.0															
Cache Peak	23.5	-1.0	28.1	26.8	42.4	26.4	26.8	38.1	26.3	23.3	38.6	38.3	23.4	23.6	23.9	24.6	26.2	36.0	40.3	24.3	23.8	72.5	0.0														
San Gabriel Mtns	67.0	-1.0	73.6	71.8	87.3	71.4	71.6	79.7	71.0	63.4	76.9	73.7	66.2	62.7	62.5	63.1	63.7	70.9	74.7	62.5	62.1	98.3	71.2	0.0													
Soda Mtns	13.3	-1.0	20.6	18.6	34.1	18.2	18.3	25.0	17.6	7.6	20.7	17.5	12.1	6.8	5.6	6.0	3.8	14.8	19.2	4.7	6.1	85.9	28.4	65.3	0.0												
Cady Mtns	16.0	-1.0	23.3	21.2	36.7	20.9	21.0	27.4	20.3	10.5	22.8	17.5	14.9	9.7	8.8	9.2	8.2	14.3	17.7	8.1	8.9	87.0	30.6	63.9	7.6	0.0											
Newberry Mtns	26.3	-1.0	33.4	31.4	46.9	31.1	31.1	37.5	30.5	21.2	32.8	26.6	25.2	20.3	19.7	20.1	19.8	23.2	26.3	19.3	19.6	93.2	39.3	64.5	20.5	13.1	0.0										
Ord Mtns	26.4	-1.0	33.5	31.5	47.0	31.2	31.3	37.6	30.6	21.3	32.9	26.8	25.3	20.4	19.8	20.3	19.9	23.4	26.5	19.4	19.7	93.2	39.4	64.4	20.7	13.4	0.7	0.0									
North Bristol Mtns	22.6	-1.0	29.7	27.7	43.1	27.3	27.4	33.1	26.7	17.3	27.7	19.8	21.5	16.4	15.6	16.0	15.3	15.9	18.7	15.2	15.8	92.3	36.7	67.3	15.6	3.7	14.1	14.5	0.0								
Old Dad Peak/ Kelso Mtns	23.3	-1.0	30.3	28.2	43.7	27.9	28.0	33.2	27.3	17.9	27.2	17.6	22.1	17.1	16.3	16.6	15.8	13.2	15.8	15.8	16.5	93.3	37.5	68.8	16.3	8.7	16.6	16.9	5.9	0.0							
New York Mtns	26.9	-1.0	34.0	31.9	47.3	31.6	31.6	36.7	31.0	21.6	30.7	20.7	25.8	20.8	20.0	20.3	19.6	16.3	18.0	19.5	20.2	96.9	41.1	72.4	20.2	12.9	20.1	20.4	10.3	6.7	0.0						
Castle Peak	28.4	-1.0	35.4	33.4	48.8	33.1	33.1	38.2	32.5	23.0	32.1	22.1	27.2	22.3	21.4	21.8	21.0	17.6	19.3	21.0	21.7	98.4	42.6	73.8	21.6	14.4	21.6	21.9	11.8	8.4	1.5	0.0					
Piute Range	29.6	-1.0	36.6	34.6	50.0	34.2	34.3	39.5	33.6	24.2	33.6	24.0	28.4	23.5	22.6	23.0	22.3	19.7	21.6	22.2	22.8	99.3	43.7	74.5	22.8	15.1	21.8	22.1	12.4	9.6	6.5	5.9	0.0				
Hackberry Mtns	27.6	-1.0	34.6	32.6	48.0	32.3	32.3	37.6	31.7	22.2	31.8	22.5	26.4	21.5	20.6	21.0	20.3	18.2	20.4	20.2	20.8	97.3	41.7	72.4	20.8	12.7	19.5	19.8	9.8	7.3	7.4	8.7	6.5	0.0			
Woods Mtns	25.5	-1.0	32.5	30.5	45.9	30.2	30.2	35.5	29.6	20.1	29.6	20.3	24.3	19.4	18.5	18.9	18.1	16.1	18.2	18.1	18.7	95.2	39.6	70.4	18.7	10.6	17.7	18.0	7.5	4.8	5.4	7.0	6.8	2.3	0.0		
Providence Mtns	23.9	-1.0	30.9	28.9	44.3	28.5	28.6	33.9	27.9	18.5	28.1	19.0	22.7	17.7	16.9	17.2	16.5	14.8	17.1	16.5	17.1	93.6	38.0	68.8	17.0	8.6	15.9	16.2	5.2	3.0	5.3	7.0	7.4	4.1	0.9	0.0	
Granite Mtns	24.0	-1.0	31.1	29.0	44.5	28.7	28.8	34.2	28.1	18.7	28.5	19.8	22.9	17.9	17.1	17.4	16.7	15.7	18.2	16.6	17.2	93.7	38.1	68.7	17.2	7.9	15.6	15.9	3.8	4.4	7.9	9.5	9.9	7.1	4.7	1.8	0.0
Clipper Mtns	31.4	-1.0	38.4	36.4	51.8	36.1	36.1	41.8	35.5	26.1	36.3	28.1	30.2	25.3	24.5	24.9	24.2	24.1	26.7	24.1	24.6	100.2	45.1	74.0	24.8	16.2	19.1	19.5	13.9	14.3	16.7	18.1	17.2	15.0	13.6	12.3	12.5
Marble Mtns	29.8	-1.0	36.9	34.9	50.3	34.5	34.6	40.3	33.9	24.5	34.9	26.9	28.7	23.7	23.0	23.4	22.7	23.0	25.6	22.5	23.1	98.6	43.6	72.2	23.3	14.6	16.9	17.2	12.4	13.3	16.1	17.5	17.0	14.6	13.1	11.5	11.3
Old Woman Mtns	32.7	-1.0	39.7	37.7	53.1	37.4	37.4	43.0	36.8	27.4	37.5	29.3	31.5	26.6	25.8	26.2	25.6	25.3	27.8	25.4	25.9	101.5	46.4	75.2	26.1	17.7	20.5	20.8	15.6	15.5	17.3	18.6	16.9	15.1	14.3	13.5	14.2
Sacramento Mtns	38.0	-1.0	45.1	43.0	58.5	42.7	42.8	48.3	42.1	32.7	42.8	34.3	36.9	31.9	31.1	31.5	30.9	30.3	32.7	30.7	31.3	107.0	51.8	80.9	31.4	23.2	26.5	26.9	20.9	20.4	21.7	22.9	20.4	19.3	18.8	18.4	19.3
Dead Mtns	54.7	-1.0	61.7	59.7	75.1	59.4	59.4	64.8	58.8	49.4	59.0	49.9	53.6	48.6	47.8	48.1	47.5	45.7	47.8	47.3	48.0	124.2	68.7	98.9	48.0	40.0	45.6	46.0	37.4	35.5	34.8	35.5	29.8	32.0	32.5	33.1	35.1
Chemuevi Mtns	63.0	-1.0	70.0	68.0	83.5	67.7	67.7	73.4	67.1	57.7	67.9	59.5	61.8	56.9	56.1	56.5	55.9	55.5	58.0	55.7	56.3	131.8	76.7	105.5	56.4	48.2	50.9	51.2	46.1	45.9	47.4	48.6	46.5	45.1	44.5	43.9	44.6
Whipple Mtns	73.0	-1.0	80.0	78.0	93.4	77.7	77.7	83.4	77.1	67.7	77.9	69.7	71.8	66.9	66.1	66.5	65.9	65.7	68.2	65.7	66.2	141.7	86.7	115.2	66.5	58.2	60.4	60.8	56.2	56.2	57.8	59.1	57.2	55.7	54.9	54.2	54.9
Turtle Mtns	43.6	-1.0	50.7	48.7	64.1	48.4	48.4	54.1	47.8	38.4	48.6	40.4	42.5	37.6	36.8	37.2	36.6	36.5	39.0	36.4	36.9	112.3	57.4	85.8	37.1	28.8	31.1	31.4	26.9	26.9	28.6	29.9	28.2	26.5	25.7	25.0	25.6
Riverside Mtns	98.6	-1.0	105.7	103.6	119.1	103.3	103.4	109.1	102.7	93.4	103.8	95.9	97.5	92.5	91.8	92.2	91.6	92.0	94.6	91.4	91.9	166.8	112.2	139.6	92.2	84.0	84.6	84.9	82.5	82.9	85.0	86.3	84.9	83.1	82.1	81.2	81.6
Big Maria Mtns	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0
Little Maria Mtns	67.4	-1.0	74.4	72.4	87.9	72.1	72.2	78.1	71.5	62.2	72.9	65.3	66.3	61.4	60.6	61.0	60.5	61.6	64.3	60.2	60.7	135.1	80.8	107.1	61.1	53.0	51.8	52.1	52.0	52.9	55.4	56.7	55.7	53.8	52.6	51.4	51.7
Iron Mtns	62.7	-1.0	69.7	67.7	83.2	67.4	67.5	73.4	66.8	57.5	68.2	60.7	61.6	56.7	55.9	56.3	55.8	56.9	59.7	55.5	56.0	130.4	76.0	102.2	56.5	48.3	46.8	47.1	47.4	48.4	50.9	52.2	51.3	49.4	48.1	46.9	47.1
Coxcombe Mtns	47.0	-1.0	54.0	52.0	67.5	51.7	51.7	57.5	51.1	41.7	52.3	44.5	45.8	40.9	40.2	40.6	40.0	40.7	43.4	39.8	40.2	115.1	60.5	87.7	40.6	32.4	32.1	32.5	31.1	31.8	34.1	35.4	34.3	32.4	31.2	30.2	30.4
Palen Mtns	43.4	-1.0	50.5	48.5	64.0	48.2	48.2	54.3	47.6	38.3	49.4	42.4	42.3	37.4	36.7	37.2	36.7	38.8	41.7	36.4	36.7	110.4	56.5	81.0	37.4	29.5	25.1	25.4	29.3	31.0	34.0	35.4	35.1	33.0	31.4	29.9	29.8
McCoy Mtns	64.7	-1.0	71.7	69.7	85.2	69.4	69.4	75.4	68.8	59.5	70.2	62.7	63.5	58.6	57.9	58.3	57.8	58.9	61.7	57.5	57.9	132.3	78.0	104.1	58.4	50.3	48.8	49.1	49.4	50.4	52.9	54.2	53.3	51.4	50.1	48.9	49.1
Chuckwalla Mtns	76.8	-1.0	83.9	81.8	97.3	81.5	81.6	87.5	80.9	71.6	82.3	74.8	75.7	70.8	70.0	70.4	69.9	71.0	73.7	69.6	70.1	144.5	90.2	116.4	70.5	62.4	61.1	61.4	61.5	62.4	64.8	66.2	65.2	63.3	62.1	60.9	61.1
Eagle Mountains	64.1	-1.0	71.1	69.1	84.6	68.8	68.8	75.0	68.2	58.9	70.0	63.0	62.9	58.1	57.4	57.8	57.4	59.4	62.3	57.0	57.4	130.8	77.1	101.1	58.0	50.2	45.9	46.2	50.0	51.7	54.6	56.0	55.7	53.6	52.0	50.5	50.4
Pinto Mtns	42.4	-1.0	49.5	47.5	63.0	47.2	47.2	53.4	46.6	37.3	48.4	41.6	41.3	36.5	35.8	36.2	35.8	38.0	40.9	35.4	35.8	109.1	55.5	79.3	36.5	28.6	23.9	24.2	28.5	30.3	33.4	34.8	34.5	32.4	30.8	29.2	29.1
Sheephole Mtns	40.9	-1.0	48.0	46.0	61.4	45.6	45.7	51.8	45.0	35.8	46.9	40.0	39.8	34.9	34.2	34.7	34.2	36.4	39.3	33.8	34.2	107.6	53.9	77.8	34.9	27.0	22.3	22.6	27.0	28.8	31.9	33.3	33.0	30.9	29.2	27.7	27.6
Sheephole Mtns	32.9	-1.0	40.0	38.0	53.4	37.7	37.7	43.8	37.1	27.7	38.8	31.9	31.8	26.9	26.2	26.6	26.2	28.3	31.2	25.8	26.2	100.3	46.1	71.8	26.8	18.6	13.8	14.2	18.5	20.5	23.6	25.1	24.9	22.7	21.0	19.4	19.2
Bullions Mtns	25.8	-1.0	32.9	30.9	46.3	30.5	30.6	36.8	29.9	20.6	31.9	25.2	24.6	19.8	19.1	19.5	19.1	21.7	24.7	18.7	19.0	93.1	38.9	64.7	19.7	11.5	4.3	4.7	11.9	14.3	17.7	19.2	19.2	16.9	15.1	13.4	13.1
Queen Mtn	41.9	-1.0	49.0	47.0	62.4	46.6	46.7	52.8	46.0	36.8	47.9	41.1	40.8	35.9	35.2	35.7	35.2	37.5	40.4	34.9	35.2	108.5	54.9	78.5	35.9	28.1	23.2	23.4	28.1	30.0	33.0	34.5	34.2	32.1	30.4	28.9	28.7
Little San Bernardino Mtns	41.0	-1.0	48.0	46.0	61.5	45.7	45.7	51.9	45.1	35.8	47.0	40.2	39.8	35.0	34.3	34.8	34.3	36.6	39.6	33.9	34.3	107.4	53.9	77.1	35.0	27.2	22.3	22.5	27.2	29.1	32.2	33.6	33.4	31.2	29.6	28.0	27.9
San Gorgonio Mtns	42.9	-1.0	50.0	48.0	63.5	47.6	47.7	54.2	47.1	38.0	49.6	43.6	41.8	37.1	36.5	37.0	36.7	40.2	43.3	36.2	36.4	106.7	55.1	71.1	37.5	30.8	23.6	23.6	31.7	33.8	37.1	38.6	38.7	36.5	34.7	33.0	32.8
San Jacinto Mtns	92.4	-1.0	99.4	97.4	112.9	97.1	97.2	103.6	96.5	87.4	99.0	92.8	91.3	86.5	85.9	86.4	86.1	89.3	92.4	85.6	85.8	156.3	104.6	121.1	86.9	80.0	73.5	73.5	80.7	82.8	86.0	87.5	87.5	85.3	83.6	81.9	81.7
Santa Rosa Mtns	94.3	-1.0	101.4	99.4	114.9	99.1	99.1	105.6	98.5	89.4	100.9	94.7	93.2	88.5	87.9	88.4	88.1	91.3	94.4	87.5	87.8	158.4	106.6	123.2	88.9	82.0	75.5	75.5	82.6	84.7	87.9	89.4	89.4	87.2	85.5	83.8	83.6
Orocopia Mtns	61.5	-1.0	68.6	66.6	82.1	66.3	66.3	72.5	65.7	56.4	67.5	60.6	60.4	55.6	54.9	55.3	54.9	57.0	59.9	54.5	54.9	128.3	74.6	98.4	55.6	47.7	43.3	43.6	47.5	49.3	52.2	53.7	53.3	51.2	49.6	48.1	48.0
W. Chocolate Mtns	63.6	-1.0	70.6	68.6	84.1	68.3	68.4	74.5	67.7	58.4	69.5	62.6	62.4	57.6	56.9	57.3	56.9	59.0	61.8	56.5	56.9	130.3	76.6	100.5	57.6	49.7	45.4	45.7	49.5	51.2	54.2	55.6	55.3	53.1	51.6	50.1	50.0
N. San Bernardino Mtns	50.1	-1.0	57.0	55.1	70.6	54.7	54.8	61.7	54.2	45.3	57.5	52.1	49.0	44.5	43.9	44.5	44.4	48.9	52.2	43.7	43.7	109.8	61.0	66.3	45.4	40.1	34.0	33.8	41.6	43.6	47.0	48.5	48.8	46.6	44.7	43.1	42.8
S. Bristol Mtns	29.1	-1.0	36.1	34.1	49.6	33.8	33.9	39.6	33.2	23.8	34.3	26.5	27.9	23.0	22.2	22.6	22.0	22.6	25.3	21.8	22.3	97.7	42.7	71.1	22.6	13.8	15.2	15.5	11.8	13.3	16.2	17.7	17.4	15.0	13.3	11.6	11.3
Rodman Mtns	8.9	-1.0	15.5	13.3	29.0	13.0	13.0	21.7	12.2	0.4	21.0	21.6	7.6	6.0	6.3	6.7	9.2	19.5	24.0	7.1	7.4	85.3	26.6	67.2	11.8	14.7	25.2	25.4	21.3	21.9	25.6	27.1	28.2	26.3	24.1	22.5	22.7
Unnamed 2	25.7	-1.0	32.8	30.8	46.2	30.4	30.5	36.8	29.8	20.5	32.0	25.6	24.5	19.7	19.0	19.5	19.1	22.1	25.2	18.6	18.9	92.7	38.7	64.1	19.8	11.9	1.6	2.0	12.7	15.2	18.7	20.1	20.3	18.0	16.2	14.4	14.1

Appendix M. Desert Bighorn Sheep Resistance Distances Across All 69 Populations (Present continued)

	Clipper Mtns	Marble Mtns	Old Woman Mtns	Sacramento Mtns	Dead Mtns	Chemuevi Mtns	Whipple Mtns	Turtle Mtns	Riverside Mtns	Big Maria Mtns	Little Maria Mtns	Iron Mtns	Coxcombe Mtns	Palen Mtns	McCoy Mtns	Chuckwalla Mtns	Eagle Mountains	Pinto Mtns	Sheephole Mtns	Sheephole Mtns	Bullions Mtns	Queen Mtn	Little San Bernardino Mtns	San Gorgonio Mtns	San Jacinto Mtns	Santa Rosa Mtns	Orocopia Mtns	W. Chocolate Mtns	N. San Bernardino Mtns	S. Bristol Mtns	Rodman Mtns	Unnamed 2
Clipper Mtns	0.0																															
Marble Mtns	5.3	0.0																														
Old Woman Mtns	9.0	11.1	0.0																													
Sacramento Mtns	16.6	18.2	8.2	0.0																												
Dead Mtns	39.3	39.7	36.6	36.7	0.0																											
Chemuevi Mtns	41.3	42.8	33.1	29.7	64.0	0.0																										
Whipple Mtns	51.3	52.8	43.3	44.0	75.7	38.4	0.0																									
Turtle Mtns	21.6	23.1	13.1	17.2	47.2	32.9	36.5	0.0																								
Riverside Mtns	78.8	79.7	72.4	76.5	104.7	89.2	84.0	66.5	0.0																							
Big Maria Mtns	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	0.0																						
Little Maria Mtns	50.1	50.1	45.6	51.3	76.8	70.1	73.9	46.4	67.9	-1.0	0.0																					
Iron Mtns	45.7	45.6	41.4	47.4	72.5	67.0	71.7	43.6	72.3	-1.0	11.6	0.0																				
Coxcombe Mtns	27.6	28.1	21.1	29.8	55.3	52.2	60.3	30.2	80.8	-1.0	43.4	36.4	0.0																			
Palen Mtns	30.5	29.0	29.5	36.0	57.8	58.9	67.1	37.9	85.4	-1.0	45.7	39.7	33.2	0.0																		
McCoy Mtns	47.7	47.6	43.5	49.4	74.5	68.8	73.3	45.3	72.2	-1.0	8.9	5.7	40.1	41.8	0.0																	
Chuckwalla Mtns	59.6	59.5	55.2	61.0	86.3	80.0	83.9	56.3	79.3	-1.0	11.6	21.1	52.9	54.8	17.1	0.0																
Eagle Mountains	51.1	49.7	49.9	56.2	78.2	78.7	86.4	57.4	101.9	-1.0	59.0	53.9	53.7	32.9	54.0	67.4	0.0															
Pinto Mtns	30.1	28.5	29.4	35.8	57.3	58.8	67.1	37.9	85.6	-1.0	46.1	40.5	34.2	8.7	42.1	55.1	23.1	0.0														
Sheephole Mtns	28.6	27.0	28.0	34.4	55.8	57.6	65.9	36.7	85.0	-1.0	46.3	40.6	33.1	7.8	42.4	55.3	28.3	3.3	0.0													
Sheephole Mtns	20.4	18.4	20.5	27.0	47.9	50.8	59.9	30.5	82.4	-1.0	47.6	42.4	27.9	17.6	44.4	56.9	40.4	17.8	15.8	0.0												
Bullions Mtns	15.6	13.2	16.8	23.0	42.8	47.2	56.6	27.2	80.2	-1.0	46.7	41.7	27.0	18.7	43.7	56.0	40.3	18.1	16.3	3.6	0.0											
Queen Mtn	29.9	28.3	29.4	35.8	57.1	59.0	67.4	38.2	86.6	-1.0	48.1	42.5	34.9	11.3	44.2	57.1	29.3	4.4	1.7	17.7	17.6	0.0										
Little San Bernardino Mtns	29.0	27.4	28.5	34.9	56.2	58.1	66.5	37.3	85.5	-1.0	46.7	41.2	34.0	10.0	42.8	55.7	25.5	1.3	1.8	17.0	16.9	1.3	0.0									
San Gorgonio Mtns	35.7	33.7	36.4	42.5	62.3	66.6	75.7	46.4	98.3	-1.0	63.5	58.4	46.2	33.9	60.3	72.8	52.9	30.8	29.4	28.5	22.7	29.3	26.4	0.0								
San Jacinto Mtns	84.2	82.3	84.7	90.8	110.9	114.6	123.6	94.3	145.2	-1.0	109.3	104.1	93.4	78.7	105.9	118.5	94.5	74.6	73.6	76.1	71.8	73.4	68.0	57.0	0.0							
Santa Rosa Mtns	86.1	84.2	86.5	92.7	112.8	116.4	125.4	96.1	146.9	-1.0	110.9	105.7	95.1	80.3	107.4	120.0	95.5	76.1	75.1	77.9	73.7	74.9	69.6	59.5	1.8	0.0						
Orocopia Mtns	48.8	47.4	47.7	54.0	75.9	76.7	84.5	55.5	100.8	-1.0	58.7	53.5	51.9	30.3	54.0	67.2	7.6	21.2	25.3	37.8	37.7	26.1	21.6	49.9	91.1	92.0	0.0					
W. Chocolate Mtns	50.7	49.3	49.5	55.8	77.8	78.4	86.2	57.2	102.0	-1.0	59.4	54.3	53.5	32.3	54.6	67.9	3.4	22.9	27.6	39.8	39.8	28.5	24.4	52.2	93.6	94.6	3.9	0.0				
N. San Bernardino Mtns	46.5	44.5	47.5	53.5	72.7	77.7	87.1	57.8	110.5	-1.0	76.7	71.7	58.4	48.7	73.6	86.0	68.3	46.3	44.9	41.0	34.2	45.2	43.3	28.4	81.5	83.9	65.5	67.7	0.0			
S. Bristol Mtns	8.5	3.3	13.2	19.9	40.5	44.6	54.5	24.9	80.7	-1.0	50.4	45.9	29.0	28.1	47.9	59.9	49.0	27.5	26.0	17.1	11.4	27.2	26.4	32.2	81.0	82.9	46.6	48.5	43.1	0.0		
Rodman Mtns	30.1	28.6	31.4	36.8	53.4	61.7	71.7	42.4	97.4	-1.0	66.2	61.5	45.8	42.3	63.5	75.6	62.9	41.3	39.8	31.8	24.6	40.8	39.8	42.0	91.4	93.4	60.4	62.4	49.3	27.8	0.0	
Unnamed 2	17.3	15.0	18.7	24.8	44.1	49.2	58.7	29.3	82.8	-1.0	49.9	45.0	30.2	23.2	46.9	59.2	44.1	22.0	20.4	11.5	1.4	21.3	20.5	22.6	72.4	74.3	41.5	43.5	33.5	13.2	24.6	0.0

Appendix N. Desert Bighorn Sheep Resistance Distances Across All 69 Populations (High Renewable Development Scenario)

	Coso Mtns	South White Mtns	Deep springs Range	Dry Mtn/Last Chance Range	Grapevine Mtns	Inyo Mtns	Tin Mtn	Funeral Mtn	Panamint Butte/ Hunter Mtn	South Panamint Mtns	Black Mtns
Coso Mtns	0.0										
South White Mtns	-1.0	0.0									
Deep springs Range	11.6	-1.0	0.0								
Dry Mtn/Last Chance Range	9.9	-1.0	2.4	0.0							
Grapevine Mtns	23.9	-1.0	15.7	14.3	0.0						
Inyo Mtns	9.3	-1.0	2.9	1.4	16.2	0.0					
Tin Mtn	9.7	-1.0	4.0	0.6	15.8	1.9	0.0				
Funeral Mtn	22.8	-1.0	20.6	18.1	26.3	18.9	17.9	0.0			
Panamint Butte/ Hunter Mtn	9.0	-1.0	4.2	1.2	16.4	1.5	0.5	18.3	0.0		
South Panamint Mtns	8.7	-1.0	13.5	10.6	25.2	11.1	11.0	20.5	10.1	0.0	
Black Mtns	26.3	-1.0	29.1	25.5	38.8	27.0	26.7	5.0	26.3	20.4	0.0
Nopah Mtns	36.5	-1.0	40.7	27.8	51.5	38.5	38.4	36.5	37.8	29.7	24.0
Argus Range	1.4	-1.0	11.9	10.1	24.1	9.5	9.9	22.5	9.1	7.7	25.5
Slate Range	10.3	-1.0	16.3	13.1	27.9	14.0	14.0	22.4	13.2	3.2	21.0
Quail Range	11.6	-1.0	17.1	13.5	28.7	14.8	14.8	22.3	14.0	3.7	19.9
Owlshead Mtns	12.8	-1.0	18.1	14.0	29.6	15.9	15.8	22.7	15.0	4.7	19.4
Avawatz Mtns	15.9	-1.0	21.3	16.1	32.8	19.0	19.0	25.6	18.2	8.5	22.0
Kingston/ Mesquite Mtns	35.5	-1.0	39.9	25.8	50.8	37.7	37.6	36.7	37.0	28.8	25.1
Clark Mtns	40.9	-1.0	45.3	30.3	56.2	43.1	43.0	42.4	42.3	34.1	31.1
Unnamed 1	12.3	-1.0	17.8	14.1	29.4	15.6	15.6	22.9	14.8	4.8	20.1
Eagle Crags	12.3	-1.0	18.0	14.2	29.6	15.7	15.7	23.5	14.9	5.4	21.2
San Rafeal Peak	115.6	-1.0	118.3	87.2	131.0	116.9	117.5	129.2	117.0	116.1	131.3
Cache Peak	27.5	-1.0	65.2	26.8	49.4	35.1	36.4	67.2	59.7	114.2	251.9
San Gabriel Mtns	122.5	-1.0	126.7	71.8	138.7	124.9	125.1	133.9	124.5	119.3	132.6
Soda Mtns	24.7	-1.0	30.1	18.6	41.5	27.8	27.8	34.0	27.0	17.4	30.0
Cady Mtns	41.4	-1.0	46.3	21.2	57.6	44.1	44.1	48.2	43.4	34.4	41.7
Newberry Mtns	84.9	-1.0	89.8	31.4	101.2	87.6	87.7	93.0	87.0	79.0	88.0
Ord Mtns	85.3	-1.0	90.2	31.5	101.7	88.1	88.1	93.5	87.4	79.5	88.5
North Bristol Mtns	44.6	-1.0	49.4	27.7	60.6	47.2	47.2	50.0	46.5	37.8	42.1
Old Dad Peak/ Kelso Mtns	43.1	-1.0	47.7	28.2	58.8	45.5	45.5	47.1	44.8	36.3	38.0
New York Mtns	47.8	-1.0	52.4	31.9	63.5	50.2	50.2	51.9	49.5	41.0	43.0
Castle Peak	50.3	-1.0	55.0	33.4	66.1	52.8	52.7	54.4	52.0	43.6	45.5
Piute Range	57.3	-1.0	62.0	34.6	73.1	59.8	59.7	61.6	59.0	50.5	53.0
Hackberry Mtns	49.1	-1.0	53.8	32.6	64.9	51.6	51.5	53.4	50.8	42.3	44.8
Woods Mtns	46.2	-1.0	50.9	30.5	62.0	48.7	48.7	50.6	48.0	39.5	41.9
Providence Mtns	44.7	-1.0	49.4	28.9	60.5	47.2	47.1	49.1	46.4	38.0	40.4
Granite Mtns	45.6	-1.0	50.3	29.0	61.4	48.1	48.0	50.1	47.3	38.8	41.6
Clipper Mtns	62.6	-1.0	67.3	36.4	78.5	65.1	65.1	67.3	64.4	55.9	58.9
Marble Mtns	62.1	-1.0	66.9	34.9	78.0	64.7	64.6	66.9	63.9	55.5	58.6
Old Woman Mtns	68.7	-1.0	73.4	37.7	84.6	71.2	71.2	73.6	70.5	62.1	65.3
Sacramento Mtns	88.5	-1.0	93.3	43.0	104.4	91.1	91.0	93.4	90.3	81.9	85.1
Dead Mtns	106.2	-1.0	110.9	59.7	122.0	108.7	108.6	110.7	107.9	99.5	102.1
Chemuevi Mtns	137.2	-1.0	141.9	68.0	153.1	139.7	139.7	142.2	139.0	130.6	134.1
Whipple Mtns	176.2	-1.0	181.0	78.0	192.2	178.8	178.7	181.4	178.0	169.7	173.5
Turtle Mtns	107.5	-1.0	112.2	48.7	123.4	110.1	110.0	112.7	109.3	101.0	104.8
Riverside Mtns	261.7	-1.0	266.5	103.6	277.7	264.3	264.3	267.5	263.6	255.3	260.1
Big Maria Mtns	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0
Little Maria Mtns	175.1	-1.0	179.9	72.4	191.3	177.8	177.8	181.9	177.1	169.0	175.4
Iron Mtns	156.0	-1.0	160.8	67.7	172.2	158.6	158.7	162.9	157.9	149.9	156.7
Coxcombe Mtns	142.7	-1.0	147.5	52.0	158.9	145.4	145.4	149.4	144.7	136.6	142.8
Palen Mtns	106.6	-1.0	111.5	48.5	122.9	109.3	109.4	114.3	108.7	100.8	108.8
McCoy Mtns	166.6	-1.0	171.4	69.7	182.8	169.3	169.3	173.5	168.6	160.5	167.2
Chuckwalla Mtns	209.3	-1.0	214.1	81.8	225.5	212.0	212.0	216.1	211.3	203.2	209.7
Eagle Mountains	145.5	-1.0	150.3	69.1	161.8	148.2	148.2	153.3	147.5	139.7	148.0
Pinto Mtns	106.1	-1.0	110.9	47.5	122.4	108.8	108.9	114.0	108.2	100.3	108.7
Sheephole Mtns	102.5	-1.0	107.3	46.0	118.8	105.2	105.2	110.4	104.5	96.7	105.1
Sheephole Mtns	91.5	-1.0	96.4	38.0	107.8	94.2	94.3	99.3	93.5	85.6	93.9
Bullions Mtns	82.7	-1.0	87.5	30.9	99.0	85.4	85.4	90.6	84.7	76.8	85.4
Queen Mtn	105.2	-1.0	110.0	47.0	121.5	107.9	107.9	113.1	107.2	99.4	107.8
Little San Bernardino Mtns	104.1	-1.0	109.0	46.0	120.4	106.9	106.9	112.1	106.2	98.4	106.8
San Gorgonio Mtns	110.1	-1.0	114.9	48.0	126.4	112.8	112.8	118.4	112.1	104.5	113.6
San Jacinto Mtns	230.5	-1.0	235.3	97.4	246.9	233.2	233.3	238.8	232.6	225.0	233.9
Santa Rosa Mtns	227.6	-1.0	232.4	99.4	243.9	230.3	230.3	235.8	229.6	222.0	230.9
Orocopia Mtns	134.3	-1.0	139.2	66.6	150.6	137.0	137.1	142.2	136.4	128.5	136.9
W. Chocolate Mtns	142.3	-1.0	147.2	68.6	158.6	145.0	145.1	150.2	144.4	136.5	144.9
N. San Bernardino Mtns	133.1	-1.0	137.9	55.1	149.5	135.8	135.9	141.9	135.2	127.8	137.5
S. Bristol Mtns	70.7	-1.0	75.4	34.1	86.6	73.2	73.2	75.5	72.5	64.0	67.2
Rodman Mtns	11.9	-1.0	16.2	13.3	27.8	13.8	13.7	22.7	12.7	0.5	23.5
Unnamed 2	83.8	-1.0	88.7	30.8	100.1	86.5	86.6	91.9	85.9	77.9	86.7

	Nopah Mtns	Argus Range	Slate Range	Quail Range	Owlshead Mtns	Avawatz Mtns	Kingston/ Mesquite Mtns	Clark Mtns	Unnamed 1	Eagle Crags	San Rafeal Peak	Cache Peak	San Gabriel Mtns	Soda Mtns
Coso Mtns														
South White Mtns														
Deep springs Range														
Dry Mtn/Last Chance Range														
Grapevine Mtns														
Inyo Mtns														
Tin Mtn														
Funeral Mtn														
Panamint Butte/ Hunter Mtn														
South Panamint Mtns														
Black Mtns														
Nopah Mtns	0.0													
Argus Range	35.5	0.0												
Slate Range	29.4	9.2	0.0											
Quail Range	27.7	10.5	2.2	0.0										
Owlshead Mtns	27.6	11.7	4.2	1.4	0.0									
Avawatz Mtns	28.1	14.8	7.2	4.6	5.4	0.0								
Kingston/ Mesquite Mtns	4.9	34.6	28.4	26.6	26.6	26.7	0.0							
Clark Mtns	12.2	39.9	33.7	31.9	31.9	31.9	1.2	0.0						
Unnamed 1	27.4	11.2	3.3	0.6	2.5	2.5	26.1	31.4	0.0					
Eagle Crags	28.9	11.2	3.4	2.1	4.0	5.6	27.7	33.0	1.5	0.0				
San Rafeal Peak	139.3	115.7	116.5	116.7	117.9	120.2	138.0	143.1	117.0	116.3	0.0			
Cache Peak	33.0	114.1	1215.6	121.5	55.1	12.8	46.5	29.7	23.5	94.8	126.6	0.0		
San Gabriel Mtns	137.3	121.9	118.5	118.0	119.3	120.7	135.2	140.0	118.0	117.1	144.4	150.3	0.0	
Soda Mtns	34.4	23.7	16.1	13.6	14.5	10.2	32.5	37.6	11.6	14.5	128.5	18.1	128.2	0.0
Cady Mtns	37.8	40.3	33.4	31.4	32.1	30.3	33.4	37.3	30.1	32.1	141.8	83.7	135.7	32.5
Newberry Mtns	86.3	83.9	77.9	76.6	77.5	77.5	82.5	86.6	76.0	76.3	170.2	123.8	139.6	82.9
Ord Mtns	86.8	84.4	78.4	77.1	78.0	78.0	83.1	87.2	76.5	76.8	170.6	124.3	139.9	83.4
North Bristol Mtns	33.8	43.7	37.0	35.1	35.6	34.4	28.1	31.6	34.1	35.8	144.5	86.9	137.6	37.8
Old Dad Peak/ Kelso Mtns	25.9	42.1	35.6	33.8	34.1	33.4	18.7	22.5	33.0	34.6	143.5	227.5	137.3	37.5
New York Mtns	31.4	46.8	40.3	38.5	38.8	38.1	24.6	27.6	37.7	39.3	147.9	5.3	141.2	42.2
Castle Peak	33.9	49.3	42.9	41.0	41.4	40.6	27.0	30.0	40.2	41.8	150.4	60.6	143.8	44.7
Piute Range	42.0	56.3	49.8	47.9	48.4	47.6	35.4	38.6	47.2	48.7	156.9	78.2	149.6	51.6
Hackberry Mtns	33.8	48.1	41.6	39.8	40.2	39.4	27.2	30.4	39.0	40.5	148.8	91.3	141.7	43.4
Woods Mtns	30.8	45.3	38.8	36.9	37.3	36.5	24.2	27.4	36.1	37.7	146.1	88.5	139.1	40.5
Providence Mtns	29.6	43.7	37.2	35.4	35.8	35.0	22.9	26.2	34.6	36.2	144.6	87.0	137.6	38.9
Granite Mtns	31.3	44.6	38.1	36.2	36.6	35.7	24.8	28.2	35.4	37.0	145.3	87.8	138.2	39.6
Clipper Mtns	48.9	61.6	55.1	53.3	53.8	53.0	42.5	45.9	52.5	54.1	161.4	104.6	152.7	57.0
Marble Mtns	48.6	61.2	54.7	52.9	53.3	52.5	42.3	45.6	52.1	53.6	160.9	104.2	152.1	56.5
Old Woman Mtns	55.6	67.7	61.3	59.5	60.0	59.2	49.3	52.7	58.7	60.2	166.6	110.5	156.3	63.3
Sacramento Mtns	75.3	87.6	81.1	79.3	79.8	79.1	69.0	72.4	78.6	80.0	186.5	130.4	176.2	83.2
Dead Mtns	91.4	105.2	98.7	96.9	97.3	96.5	84.8	88.1	96.1	97.7	205.5	148.3	197.5	100.6
Chemuevi Mtns	124.6	136.2	129.8	128.0	128.5	127.8	118.5	121.8	127.3	128.7	234.4	178.9	223.0	132.0
Whipple Mtns	164.6	175.3	168.9	167.1	167.7	167.0	158.6	162.0	166.4	167.7	272.6	217.7	259.7	171.2
Turtle Mtns	95.8	106.5	100.1	98.4	98.9	98.3	89.8	93.2	97.7	99.0	203.9	149.0	191.0	102.5
Riverside Mtns	252.4	260.8	254.5	252.8	253.4	252.8	246.8	250.3	252.1	253.3	355.5	302.7	338.4	257.3
Big Maria Mtns	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0
Little Maria Mtns	170.2	174.2	168.0	166.5	167.3	166.9	165.4	169.1	165.9	166.7	264.3	215.1	239.2	171.8
Iron Mtns	151.9	155.1	148.9	147.5	148.2	147.9	147.2	151.0	146.9	147.6	244.3	195.8	217.7	152.9
Coxcombe Mtns	137.3	141.8	135.6	134.1	134.8	134.5	132.4	136.1	133.5	134.3	232.5	182.8	208.6	139.3
Palen Mtns	105.9	105.7	99.7	98.4	99.2	99.1	101.8	105.7	97.8	98.3	191.3	145.6	158.7	104.3
McCoy Mtns	162.3	165.7	159.6	158.1	158.8	158.5	157.6	161.3	157.5	158.2	255.1	206.4	228.9	163.4
Chuckwalla Mtns	204.6	208.4	202.2	200.7	201.5	201.2	199.8	203.5	200.1	200.9	298.2	249.2	272.8	206.0
Eagle Mountains	145.4	144.6	138.6	137.3	138.2	138.1	141.4	145.4	136.8	137.2	228.6	184.2	193.3	143.4
Pinto Mtns	106.2	105.2	99.3	97.9	98.8	98.8	102.2	106.2	97.4	97.8	189.2	144.8	153.7	104.1
Sheephole Mtns	102.5	101.6	95.6	94.3	95.2	95.1	98.6	102.6	93.8	94.2	185.8	141.2	150.6	100.4
Sheephole Mtns	91.3	90.6	84.5	83.2	84.1	84.0	87.3	91.3	82.6	83.1	176.8	130.6	145.6	89.2
Bullions Mtns	83.3	81.7	75.7	74.4	75.3	75.2	79.4	83.4	73.8	74.2	168.0	121.7	137.2	80.5
Queen Mtn	105.4	104.2	98.3	97.0	97.9	97.8	101.4	105.4	96.5	96.8	188.0	143.8	152.0	103.2
Little San Bernardino Mtns	104.4	103.2	97.3	96.0	96.9	96.8	100.4	104.5	95.5	95.8	186.9	142.8	150.7	102.2
San Gorgonio Mtns	112.2	109.2	103.5	102.2	103.2	103.3	108.5	112.6	101.8	101.9	187.9	147.7	142.7	108.9
San Jacinto Mtns	232.1	229.7	223.9	222.6	223.6	223.6	228.4	232.5	222.2	222.4	309.3	268.4	265.7	229.2
Santa Rosa Mtns	229.1	226.7	220.9	219.7	220.6	220.7	225.4	229.4	219.2	219.4	306.6	265.5	263.3	226.2
Orocopia Mtns	134.4	133.4	127.5	126.2	127.1	127.0	130.4	134.4	125.6	126.0	217.4	173.0	181.7	132.3
W. Chocolate Mtns	142.3	141.4	135.5	134.2	135.1	135.0	138.3	142.3	133.6	134.0	225.4	181.0	189.9	140.3
N. San Bernardino Mtns	137.0	132.3	126.8	125.7	126.7	126.9	133.5	137.7	125.3	125.3	205.2	169.7	149.0	132.8
S. Bristol Mtns	57.4	69.7	63.2	61.4	61.9	61.1	51.1	54.5	60.6	62.1	169.3	112.7	160.2	65.1
Rodman Mtns	33.6	11.0	7.9	8.5	9.4	13.1	32.7	38.1	9.5	10.0	119.5	24.0	123.1	21.9
Unnamed 2	84.9	82.9	76.8	75.5	76.4	76.3	81.1	85.2	74.9	75.2	169.1	122.8	138.4	81.7

	Cady Mtns	Newberry Mtns	Ord Mtns	North Bristol Mtns	Old Dad Peak/ Kelso Mtns	New York Mtns	Castle Peak	Piute Range	Hackberry Mtns	Woods Mtns	Providence Mtns	Granite Mtns
Coso Mtns												
South White Mtns												
Deep springs Range												
Dry Mtn/Last Chance Range												
Grapevine Mtns												
Inyo Mtns												
Tin Mtn												
Funeral Mtn												
Panamint Butte/ Hunter Mtn												
South Panamint Mtns												
Black Mtns												
Nopah Mtns												
Argus Range												
Slate Range												
Quail Range												
Owlshead Mtns												
Avawatz Mtns												
Kingston/ Mesquite Mtns												
Clark Mtns												
Unnamed 1												
Eagle Crags												
San Rafeal Peak												
Cache Peak												
San Gabriel Mtns												
Soda Mtns												
Cady Mtns	0.0											
Newberry Mtns	74.4	0.0										
Ord Mtns	75.1	0.7	0.0									
North Bristol Mtns	12.2	75.1	75.8	0.0								
Old Dad Peak/ Kelso Mtns	24.6	76.9	77.5	13.3	0.0							
New York Mtns	28.5	79.9	80.5	16.5	8.1	0.0						
Castle Peak	31.2	82.6	83.2	19.3	10.8	1.6	0.0					
Piute Range	36.8	86.8	87.4	24.4	18.1	16.9	19.7	0.0				
Hackberry Mtns	28.4	79.1	79.8	15.9	9.7	9.1	11.9	9.7	0.0			
Woods Mtns	25.6	76.9	77.6	13.0	6.6	6.0	8.8	11.6	2.3	0.0		
Providence Mtns	23.4	75.4	76.0	10.3	5.1	6.0	8.8	13.2	4.5	0.9	0.0	
Granite Mtns	22.5	75.6	76.3	8.4	7.6	9.5	12.3	16.8	8.3	5.3	2.0	0.0
Clipper Mtns	41.4	86.6	87.3	28.8	25.8	27.0	29.8	31.8	24.3	22.4	20.8	21.1
Marble Mtns	40.6	85.8	86.5	27.9	25.6	27.1	29.9	32.6	24.8	22.7	20.6	20.2
Old Woman Mtns	48.6	87.3	88.0	37.1	33.2	33.8	36.6	35.1	29.3	28.9	28.6	30.0
Sacramento Mtns	68.6	107.6	108.3	57.1	52.9	53.2	56.0	51.9	48.2	48.2	48.3	50.1
Dead Mtns	85.8	133.4	134.0	73.6	67.8	67.0	69.8	55.7	60.2	61.7	63.0	66.2
Chemuevi Mtns	117.6	152.3	153.1	106.6	102.8	103.3	106.1	103.7	98.7	98.4	98.3	99.9
Whipple Mtns	157.2	186.2	186.9	147.0	143.5	144.2	147.0	145.4	140.0	139.5	139.2	140.6
Turtle Mtns	88.5	117.6	118.4	78.1	74.7	75.5	78.2	76.9	71.3	70.7	70.4	71.7
Riverside Mtns	244.4	257.5	258.3	236.0	233.4	234.6	237.3	236.9	231.0	230.1	229.6	230.7
Big Maria Mtns	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0
Little Maria Mtns	160.8	144.4	145.3	156.0	155.1	157.0	159.7	161.2	154.5	153.1	152.2	152.9
Iron Mtns	142.3	120.3	121.2	138.1	137.5	139.5	142.2	144.1	137.3	135.8	134.7	135.4
Coxcombe Mtns	128.0	113.8	114.7	122.8	121.7	123.5	126.3	127.8	121.0	119.7	118.7	119.5
Palen Mtns	95.2	50.5	51.5	93.7	94.5	97.1	99.7	103.1	95.7	93.8	92.4	92.8
McCoy Mtns	152.7	132.3	133.2	148.4	147.7	149.7	152.4	154.2	147.4	146.0	144.9	145.6
Chuckwalla Mtns	195.2	177.5	178.5	190.5	189.6	191.5	194.2	195.9	189.2	187.7	186.8	187.5
Eagle Mountains	134.8	88.2	89.2	133.8	134.6	137.3	140.0	143.6	136.1	134.1	132.7	133.1
Pinto Mtns	95.5	47.8	48.8	94.6	95.5	98.2	100.9	104.5	97.1	95.1	93.6	94.0
Sheephole Mtns	91.8	43.9	44.8	90.9	91.8	94.5	97.2	100.8	93.4	91.3	89.9	90.3
Sheephole Mtns	79.9	26.4	27.6	79.2	80.4	83.2	85.9	89.6	82.1	80.0	78.5	78.8
Bullions Mtns	71.2	7.0	8.3	71.5	73.1	76.0	78.7	82.7	75.1	72.9	71.4	71.7
Queen Mtn	94.7	46.5	47.5	93.9	94.8	97.6	100.2	103.9	96.4	94.4	93.0	93.3
Little San Bernardino Mtns	93.7	45.7	46.6	92.9	93.8	96.6	99.3	102.9	95.5	93.4	92.0	92.4
San Gorgonio Mtns	102.2	53.0	53.7	102.1	103.1	106.1	108.8	112.8	105.2	103.1	101.6	102.0
San Jacinto Mtns	222.0	174.6	175.5	221.7	222.6	225.5	228.2	232.1	224.6	222.5	221.0	221.4
Santa Rosa Mtns	219.0	171.6	172.4	218.6	219.6	222.4	225.1	229.0	221.5	219.4	217.9	218.3
Orocopia Mtns	123.8	76.6	77.6	122.8	123.7	126.4	129.1	132.6	125.2	123.2	121.8	122.2
W. Chocolate Mtns	131.7	84.9	85.8	130.7	131.6	134.3	136.9	140.5	133.1	131.1	129.7	130.0
N. San Bernardino Mtns	128.1	85.0	85.5	128.3	129.2	132.3	135.0	139.3	131.7	129.4	128.0	128.4
S. Bristol Mtns	49.2	93.0	93.7	36.7	34.6	36.1	38.9	41.8	34.0	31.8	29.6	29.1
Rodman Mtns	38.7	83.2	83.6	42.0	40.4	45.1	47.7	54.6	46.5	43.6	42.1	42.9
Unnamed 2	72.8	2.6	3.9	73.4	75.2	78.2	80.9	85.0	77.4	75.2	73.6	73.9

Appendix N. Desert Bighorn Sheep Resistance Distances Across All 69 Populations (High Renewable Development Scenario Continued)

	Clipper Mtns	Marble Mtns	Old Woman Mtns	Sacramento Mtns	Dead Mtns	Chemuevi Mtns	Whipple Mtns	Turtle Mtns	Riverside Mtns	Big Maria Mtns	Little Maria Mtns	Iron Mtns	Coxcombe Mtns	Palen Mtns	McCoy Mtns	Chuckwalla Mtns	Eagle Mountains	Pinto Mtns	Sheephole Mtns	Sheephole Mtns	Bullions Mtns	Queen Mtn	Little San Bernardino Mtns	San Gorgonio Mtns	San Jacinto Mtns	Santa Rosa Mtns	Orocopia Mtns	W. Chocolate Mtns	N. San Bernardino Mtns	S. Bristol Mtns	Rodman Mtns	Unnamed 2
Clipper Mtns	0.0																															
Marble Mtns	14.0	0.0																														
Old Woman Mtns	27.8	32.8	0.0																													
Sacramento Mtns	51.6	55.7	28.8	0.0																												
Dead Mtns	78.2	79.7	75.8	72.2	0.0																											
Chemuevi Mtns	100.0	104.3	76.0	58.5	136.9	0.0																										
Whipple Mtns	140.6	144.7	117.0	118.7	182.0	113.5	0.0																									
Turtle Mtns	71.3	75.5	46.9	57.3	114.9	80.2	88.1	0.0																								
Riverside Mtns	232.4	235.6	212.9	223.4	276.2	243.0	223.5	185.1	0.0																							
Big Maria Mtns	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	0.0																						
Little Maria Mtns	158.1	159.6	147.0	163.6	203.9	197.3	213.0	146.5	224.7	-1.0	0.0																					
Iron Mtns	141.3	142.4	131.8	149.3	187.3	185.2	204.8	137.1	234.3	-1.0	41.5	0.0																				
Coxcombe Mtns	123.9	125.5	110.9	133.1	171.0	173.1	200.7	131.6	255.9	-1.0	106.5	69.0	0.0																			
Palen Mtns	101.5	101.2	98.7	118.6	148.5	160.9	191.1	122.7	251.9	-1.0	118.9	90.6	93.9	0.0																		
McCoy Mtns	151.3	152.5	141.4	158.7	197.3	193.9	212.3	145.0	236.7	-1.0	32.2	20.2	90.2	104.1	0.0																	
Chuckwalla Mtns	192.8	194.2	182.1	198.9	238.6	233.0	249.5	182.9	265.1	-1.0	42.9	73.5	139.3	151.3	59.7	0.0																
Eagle Mountains	142.3	141.9	140.2	160.2	189.2	202.9	233.7	165.3	296.1	-1.0	166.2	140.5	143.9	66.7	151.3	198.1	0.0															
Pinto Mtns	103.3	102.9	101.5	121.6	150.3	164.6	195.8	127.4	259.6	-1.0	132.4	106.0	106.7	25.8	118.2	164.8	37.7	0.0														
Sheephole Mtns	99.6	99.1	97.8	117.9	146.6	160.9	192.3	123.8	256.3	-1.0	129.7	103.2	103.2	22.2	115.6	162.2	47.3	5.1	0.0													
Sheephole Mtns	88.3	87.5	87.4	107.8	135.6	151.6	184.2	115.7	252.0	-1.0	132.3	106.8	100.9	31.3	119.2	165.1	74.4	33.7	28.3	0.0												
Bullions Mtns	82.0	81.2	82.2	102.5	129.1	147.0	180.3	111.8	250.3	-1.0	134.4	109.7	103.4	37.3	121.9	167.4	77.1	36.6	32.1	7.3	0.0											
Queen Mtn	102.8	102.2	101.1	121.2	149.7	164.3	195.7	127.3	260.1	-1.0	134.0	107.7	107.8	28.3	120.0	166.5	47.8	5.5	2.0	33.3	35.6	0.0										
Little San Bernardino Mtns	101.8	101.3	100.1	120.2	148.7	163.3	194.7	126.3	259.0	-1.0	132.7	106.5	106.7	27.0	118.7	165.2	43.7	1.4	2.3	32.5	34.8	1.3	0.0									
San Gorgonio Mtns	112.4	111.8	112.1	132.2	159.1	176.3	209.1	140.6	277.3	-1.0	158.4	133.3	130.3	59.4	145.4	191.2	85.5	45.3	42.9	52.6	47.5	42.2	39.5	0.0								
San Jacinto Mtns	231.5	230.9	230.6	250.7	278.2	294.4	326.7	258.2	393.3	-1.0	271.5	246.1	244.5	170.7	258.1	304.1	186.5	152.5	151.6	169.1	167.2	150.8	147.3	143.4	0.0							
Santa Rosa Mtns	228.4	227.8	227.5	247.6	275.1	291.2	323.4	254.9	389.9	-1.0	267.8	242.4	241.0	166.8	254.3	300.4	181.7	148.3	147.5	165.7	164.0	146.8	143.1	141.7	3.0	0.0						
Orocopia Mtns	131.5	131.0	129.5	149.5	178.4	192.4	223.4	155.0	286.5	-1.0	157.9	132.0	134.2	55.9	143.4	190.1	22.2	29.3	35.2	63.0	65.6	35.5	30.8	73.3	172.6	167.5	0.0					
W. Chocolate Mtns	139.3	138.9	137.2	157.2	186.2	200.0	230.9	162.5	293.6	-1.0	164.2	138.5	141.3	63.7	149.5	196.2	9.1	36.0	43.8	71.1	73.8	44.2	39.9	81.9	182.0	177.1	12.3	0.0				
N. San Bernardino Mtns	139.4	138.8	139.8	159.9	185.8	204.4	237.8	169.3	307.8	-1.0	192.1	167.7	163.6	96.3	179.6	225.1	124.4	84.3	81.8	87.4	80.9	81.5	79.3	48.2	185.0	183.2	112.3	120.9	0.0			
S. Bristol Mtns	25.1	10.9	43.0	65.6	89.0	114.2	154.5	85.4	244.9	-1.0	167.9	150.5	133.9	108.6	160.7	202.5	149.2	110.2	106.4	94.6	88.3	109.5	108.6	119.2	238.3	235.1	138.3	146.2	146.2	0.0		
Rodman Mtns	60.0	59.6	66.2	86.0	103.6	134.7	173.8	105.1	259.4	-1.0	173.1	154.0	140.7	104.9	164.7	207.3	143.8	104.4	100.8	89.7	80.9	103.5	102.5	108.6	229.0	226.1	132.7	140.6	131.9	68.1	0.0	
Unnamed 2	84.7	83.9	85.3	105.6	131.6	150.3	184.0	115.5	255.0	-1.0	141.4	117.2	110.8	46.9	129.2	174.5	84.8	44.4	40.3	22.2	2.1	43.1	42.2	50.4	171.7	168.7	73.2	81.4	83.0	91.1	82.1	0.0

Appendix O. Desert Bighorn Sheep Percent Change in Resistance Distances Across All 69 Populations (from Present to High Renewable Development)

	Coso Mtns	South White Mtns	Deep springs Range	Dry Mtn/Last Chance Range	Grapevine Mtns	Inyo Mtns	Tin Mtn	Funeral Mtn	Panamint Butte/ Hunter Mtn	South Panamint Mtns	Black Mtns	Nopah Mtns	Argus Range	Slate Range	Quail Range	Owlshead Mtns	Avawatz Mtns	Kingston/ Mesquite Mtns	Clark Mtns	Unnamed 1	Eagle Crags	San Rafeal Peak	Cache Peak	San Gabriel Mtns	Soda Mtns	Cady Mtns	Newberry Mtns	Ord Mtns	North Bristol Mtns	Old Dad Peak/ Kelso Mtns	New York Mtns	Castle Peak	Piute Range	Hackberry Mtns	Woods Mtns	Providence Mtns	Granite Mtns
Coso Mtns	0.00%																																				
South White Mtns	0.00%	0.00%																																			
Deep springs Range	-4.03%	0.00%	0.00%																																		
Dry Mtn/Last Chance Range	-2.12%	0.00%	-4.42%	0.00%																																	
Grapevine Mtns	-8.17%	0.00%	-9.83%	-10.63%	0.00%																																
Inyo Mtns	-3.61%	0.00%	-6.84%	13.51%	-10.48%	0.00%																															
Tin Mtn	-1.91%	0.00%	-2.14%	2.74%	-11.06%	13.76%	0.00%																														
Funeral Mtn	5.23%	0.00%	-0.36%	0.17%	-8.23%	1.17%	0.39%	0.00%																													
Panamint Butte/ Hunter Mtn	-2.42%	0.00%	-0.73%	6.34%	-10.38%	19.89%	3.47%	0.77%	0.00%																												
South Panamint Mtns	65.40%	0.00%	6.30%	8.30%	-4.36%	8.98%	7.89%	5.00%	6.48%	0.00%																											
Black Mtns	16.16%	0.00%	5.23%	5.98%	-2.26%	6.50%	6.00%	17.43%	6.06%	13.90%	0.00%																										
Nopah Mtns	57.10%	0.00%	36.13%	39.08%	19.63%	39.85%	39.39%	23.10%	40.16%	67.33%	16.71%	0.00%																									
Argus Range	0.80%	0.00%	-1.64%	0.57%	-7.16%	-0.71%	0.79%	6.71%	0.43%	96.73%	18.02%	60.99%	0.00%																								
Slate Range	37.69%	0.00%	7.36%	9.42%	-2.74%	9.68%	9.31%	7.54%	8.81%	93.82%	16.13%	70.24%	46.54%	0.00%																							
Quail Range	43.18%	0.00%	9.89%	12.21%	-1.43%	12.66%	12.17%	7.59%	11.87%	92.32%	13.94%	69.59%	52.84%	126.45%	0.00%																						
Owlshead Mtns	47.36%	0.00%	12.96%	15.62%	0.32%	16.19%	15.65%	8.62%	15.57%	100.64%	12.78%	68.46%	57.11%	94.49%	78.88%	0.00%																					
Avawatz Mtns	47.19%	0.00%	17.44%	20.33%	3.75%	20.90%	20.45%	13.43%	20.61%	70.57%	19.83%	76.63%	54.43%	70.18%	60.55%	76.25%	0.00%																				
Kingston/ Mesquite Mtns	68.66%	0.00%	43.15%	46.89%	23.58%	47.80%	47.30%	28.57%	48.33%	84.35%	23.54%	61.29%	73.63%	88.33%	88.57%	87.15%	97.78%	0.00%																			
Clark Mtns	60.37%	0.00%	40.09%	43.05%	23.31%	43.80%	43.37%	27.28%	44.16%	70.20%	22.38%	26.35%	64.03%	72.94%	72.09%	71.04%	77.65%	5.12%	0.00%																		
Unnamed 1	40.81%	0.00%	10.24%	12.51%	-1.00%	12.94%	12.49%	7.98%	12.24%	70.34%	14.25%	70.46%	49.03%	72.06%	31.07%	70.18%	29.59%	90.09%	72.82%	0.00%																	
Eagle Crags	41.48%	0.00%	10.93%	13.35%	-0.55%	13.75%	13.36%	8.91%	13.19%	70.96%	15.63%	69.74%	49.56%	93.09%	45.21%	59.64%	51.15%	88.28%	72.72%	21.58%	0.00%																
San Rafeal Peak	38.67%	0.00%	33.43%	34.63%	27.46%	34.72%	34.83%	32.81%	35.11%	41.81%	35.93%	46.16%	39.51%	42.39%	42.43%	42.80%	43.45%	48.51%	47.45%	42.41%	42.48%	0.00%															
Cache Peak	16.65%	0.00%	#######	-21.09%	16.39%	33.03%	35.79%	76.49%	#######	390.40%	553.28%	-13.78%	388.33%	5041.68%	408.33%	123.75%	-51.11%	29.12%	-26.43%	-3.28%	298.24%	74.57%	0.00%														
San Gabriel Mtns	82.69%	0.00%	72.27%	74.54%	58.91%	74.89%	74.81%	67.89%	75.43%	88.07%	72.28%	86.28%	84.27%	88.94%	88.79%	88.91%	89.48%	90.66%	87.46%	88.82%	88.49%	46.91%	111.15%	0.00%													
Soda Mtns	85.73%	0.00%	45.73%	51.32%	21.76%	52.41%	51.90%	35.93%	53.27%	129.02%	44.52%	96.61%	95.26%	138.20%	143.02%	143.17%	169.36%	118.89%	95.43%	146.33%	138.39%	49.70%	-36.23%	96.44%	0.00%												
Cady Mtns	157.68%	0.00%	99.04%	#######	56.83%	#######	#######	75.81%	#######	226.86%	83.18%	115.78%	171.27%	245.83%	258.48%	248.95%	271.43%	133.45%	110.53%	271.27%	260.81%	62.91%	173.70%	112.33%	328.96%	0.00%											
Newberry Mtns	222.51%	0.00%	#######	#######	#######	#######	#######	#######	#######	272.81%	168.33%	224.44%	233.28%	283.36%	289.48%	284.86%	291.53%	256.19%	229.56%	294.10%	290.16%	82.52%	215.14%	116.36%	303.54%	468.59%	0.00%										
Ord Mtns	222.86%	0.00%	#######	#######	#######	#######	#######	#######	#######	272.81%	168.57%	223.97%	233.58%	283.32%	289.30%	284.66%	291.06%	255.23%	228.82%	293.81%	290.09%	82.95%	215.73%	117.35%	302.79%	460.07%	4.84%	0.00%									
North Bristol Mtns	97.46%	0.00%	66.48%	71.64%	40.61%	72.75%	72.24%	50.99%	73.77%	119.37%	52.16%	70.96%	103.47%	124.92%	124.54%	122.45%	125.36%	76.12%	69.27%	125.24%	127.16%	56.64%	137.02%	104.33%	141.89%	233.07%	431.30%	423.52%	0.00%								
Old Dad Peak/ Kelso Mtns	85.26%	0.00%	57.60%	62.01%	34.70%	63.02%	62.52%	41.93%	63.82%	103.15%	39.66%	47.28%	90.52%	107.95%	107.48%	105.55%	110.68%	41.48%	42.17%	108.56%	109.51%	53.78%	507.14%	99.47%	129.58%	184.63%	362.07%	357.42%	124.09%	0.00%							
New York Mtns	77.35%	0.00%	54.44%	58.15%	34.25%	58.99%	58.56%	41.35%	59.61%	90.18%	40.20%	51.53%	81.49%	93.50%	92.48%	91.33%	94.50%	51.04%	53.36%	92.83%	94.15%	52.57%	-87.06%	95.20%	109.19%	121.29%	297.46%	294.65%	61.12%	20.43%	0.00%						
Castle Peak	77.19%	0.00%	55.26%	58.86%	35.45%	59.67%	59.26%	42.62%	60.28%	89.18%	41.77%	53.14%	81.11%	92.24%	91.25%	90.19%	93.11%	53.16%	55.35%	91.54%	92.81%	52.91%	42.30%	94.83%	106.82%	116.31%	282.57%	280.17%	62.72%	28.18%	5.02%	0.00%					
Piute Range	93.69%	0.00%	69.30%	73.60%	46.21%	74.51%	74.10%	56.10%	75.37%	108.71%	57.77%	74.95%	98.10%	112.25%	111.96%	110.68%	113.80%	79.73%	78.52%	112.59%	113.33%	57.97%	79.05%	100.81%	126.21%	143.54%	298.12%	295.46%	96.73%	88.12%	158.52%	232.02%	0.00%				
Hackberry Mtns	77.93%	0.00%	55.30%	58.99%	35.15%	59.82%	59.40%	42.17%	60.45%	90.45%	40.94%	50.41%	81.99%	93.75%	92.63%	91.45%	94.19%	49.04%	49.19%	92.93%	94.48%	52.96%	119.09%	95.70%	108.54%	123.30%	305.08%	301.94%	62.50%	32.97%	22.96%	37.08%	49.53%	0.00%			
Woods Mtns	81.55%	0.00%	56.66%	60.69%	35.18%	61.60%	61.14%	42.60%	62.31%	96.36%	41.32%	51.81%	86.13%	100.25%	99.31%	97.87%	101.24%	50.54%	50.38%	99.81%	101.28%	53.40%	123.57%	97.56%	117.08%	142.14%	335.54%	331.53%	72.64%	36.45%	11.58%	25.69%	69.93%	0.50%	0.00%		
Providence Mtns	87.44%	0.00%	59.90%	64.38%	36.65%	65.38%	64.89%	44.80%	66.21%	105.23%	43.79%	55.70%	92.65%	109.88%	109.30%	107.50%	111.52%	55.19%	53.62%	110.11%	111.41%	54.45%	129.12%	100.11%	128.66%	172.76%	373.49%	368.23%	97.70%	68.07%	11.95%	25.11%	78.36%	7.88%	-3.04%	0.00%	
Granite Mtns	89.77%	0.00%	61.83%	66.42%	38.09%	67.44%	66.94%	46.59%	68.30%	108.00%	45.90%	57.94%	95.05%	112.77%	112.19%	110.33%	114.03%	58.02%	55.05%	112.99%	114.45%	55.17%	130.61%	101.21%	130.84%	184.10%	385.60%	379.80%	119.93%	73.04%	20.18%	28.99%	69.30%	16.97%	13.54%	12.42%	0.00%
Clipper Mtns	99.66%	0.00%	75.24%	79.63%	51.37%	80.56%	80.14%	61.20%	81.46%	114.51%	62.38%	73.97%	104.01%	118.21%	117.77%	116.23%	118.48%	76.09%	71.90%	118.35%	119.68%	61.04%	131.86%	106.15%	129.86%	155.05%	352.95%	348.53%	106.62%	80.40%	61.98%	64.76%	84.68%	62.02%	64.63%	68.79%	68.66%
Marble Mtns	108.38%	0.00%	81.26%	86.19%	55.06%	87.23%	86.77%	66.02%	88.28%	125.95%	67.80%	80.82%	113.30%	130.32%	130.19%	128.29%	130.85%	83.98%	78.41%	131.00%	132.29%	63.24%	139.19%	110.56%	142.59%	178.41%	408.74%	402.41%	124.82%	92.20%	68.78%	70.73%	92.32%	69.52%	73.36%	78.82%	78.37%
Old Woman Mtns	110.36%	0.00%	84.86%	89.64%	59.18%	90.61%	90.21%	70.94%	91.66%	126.76%	73.99%	90.01%	114.93%	130.57%	130.66%	129.11%	131.77%	95.16%	89.78%	131.50%	132.19%	64.14%	138.11%	107.76%	142.60%	173.90%	326.09%	322.69%	137.48%	113.82%	95.60%	97.05%	108.23%	93.91%	101.75%	111.33%	111.76%
Sacramento Mtns	132.92%	0.00%	#######	#######	78.55%	#######	#######	93.22%	#######	150.34%	98.97%	119.46%	137.53%	154.07%	154.79%	153.26%	156.06%	127.90%	121.29%	155.84%	155.86%	74.31%	151.57%	117.81%	164.66%	196.09%	305.53%	303.20%	172.84%	158.74%	145.29%	144.79%	154.29%	149.88%	156.21%	163.00%	159.31%
Dead Mtns	94.10%	0.00%	79.57%	82.41%	62.37%	82.98%	82.74%	70.82%	83.56%	101.47%	72.99%	83.18%	96.44%	103.11%	102.77%	102.18%	103.45%	85.69%	84.11%	102.98%	103.55%	65.43%	115.83%	99.61%	109.55%	114.48%	192.20%	191.62%	96.89%	91.29%	92.67%	96.63%	86.62%	87.93%	89.47%	90.49%	88.37%
Chemuevi Mtns	117.77%	0.00%	#######	#######	83.40%	#######	#######	93.81%	#######	126.29%	97.55%	109.32%	120.24%	128.04%	128.08%	127.42%	128.67%	113.27%	110.03%	128.46%	128.72%	77.86%	133.06%	111.44%	133.79%	144.15%	199.24%	198.73%	131.35%	124.16%	118.19%	118.38%	122.96%	118.86%	121.38%	124.17%	123.69%
Whipple Mtns	141.53%	0.00%	#######	#######	#######	#######	#######	#######	#######	150.69%	122.70%	136.12%	144.03%	152.45%	152.80%	152.12%	153.43%	141.21%	137.39%	153.30%	153.26%	92.42%	151.18%	125.49%	157.66%	170.27%	208.05%	207.61%	161.38%	155.49%	149.39%	148.77%	154.07%	151.32%	153.87%	156.67%	156.03%
Turtle Mtns	146.30%	0.00%	#######	#######	92.48%	#######	#######	#######	#######	163.11%	115.54%	137.10%	150.66%	166.52%	167.44%	166.06%	168.63%	146.35%	139.26%	168.50%	168.23%	81.50%	159.78%	122.59%	175.97%	206.73%	278.75%	277.16%	190.62%	177.87%	163.58%	161.61%	172.96%	168.62%	174.96%	182.05%	180.37%
Riverside Mtns	165.45%	0.00%	#######	#######	#######	#######	#######	#######	#######	173.51%	150.55%	163.19%	167.57%	174.96%	175.43%	174.88%	175.98%	168.19%	164.54%	175.91%	175.67%	#######	169.87%	142.40%	179.04%	190.92%	204.39%	204.19%	186.08%	181.51%	176.10%	175.09%	179.17%	177.90%	180.25%	182.81%	182.67%
Big Maria Mtns	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Little Maria Mtns	159.88%	0.00%	#######	#######	#######	#######	#######	#######	#######	171.80%	140.79%	160.53%	162.93%	173.87%	174.72%	174.05%	175.86%	168.67%	163.16%	175.53%	174.80%	95.56%	166.27%	123.40%	181.00%	203.32%	178.99%	179.10%	199.92%	192.90%	183.59%	181.58%	189.27%	187.18%	191.20%	195.85%	196.04%
Iron Mtns	148.85%	0.00%	#######	#######	#######	#######	#######	#######	#######	160.81%	129.74%	150.16%	151.92%	162.87%	163.68%	163.07%	164.97%	158.46%	152.99%	164.49%	163.70%	87.37%	157.40%	113.05%	170.77%	194.21%	156.84%	157.17%	191.27%	183.97%	174.25%	172.27%	180.82%	178.08%	182.20%	187.10%	187.39%
Coxcombe Mtns	203.96%	0.00%	#######	#######	#######	#######	#######	#######	#######	227.31%	173.22%	208.28%	209.46%	231.50%	233.92%	232.34%	236.01%	225.19%	213.85%	235.77%	233.87%	#######	202.33%	137.83%	242.89%	295.41%	254.03%	253.31%	295.25%	282.93%	262.57%	256.43%	272.12%	273.52%	282.92%	293.65%	292.43%
Palen Mtns	145.46%	0.00%	#######	#######	92.13%	#######	#######	#######	#######	163.15%	120.46%	149.65%	149.84%	166.26%	167.63%	166.78%	169.69%	162.32%	153.65%	168.95%	167.47%	73.35%	157.54%	96.05%	178.84%	223.10%	100.84%	102.61%	220.18%	204.32%	185.41%	181.47%	193.63%	190.45%	198.87%	209.26%	211.86%
McCoy Mtns	157.68%	0.00%	#######	#######	#######	#######	#######	#######	#######	169.99%	138.27%	158.87%	160.82%	172.12%	173.01%	172.34%	174.24%	167.38%	161.67%	173.85%	173.05%	92.78%	164.58%	119.83%	179.70%	203.46%	171.06%	171.28%	200.43%	193.06%	183.22%	181.09%	189.29%	187.04%	191.28%	196.24%	196.52%
Chuckwalla Mtns	172.58%	0.00%	#######	#######	#######	#######	#######	#######	#######	183.87%	154.89%	173.64%	175.44%	185.80%	186.67%	186.02%	187.68%	181.42%	176.13%	187.43%	186.72%	#######	176.40%	134.39%	192.04%	212.54%	190.58%	190.64%	209.94%	203.82%	195.44%	193.47%	200.25%	198.80%	202.44%	206.60%	206.75%
Eagle Mountains	127.12%	0.00%	#######	#######	91.26%	#######	#######	#######	#######	137.11%	111.48%	130.72%	129.74%	138.72%	139.31%	139.01%	140.73%	138.03%	133.42%	139.98%	139.12%	74.77%	138.84%	91.16%	147.08%	168.73%	91.97%	92.98%	167.64%	160.47%	151.42%	149.81%	157.80%	154.20%	157.96%	162.70%	163.94%
Pinto Mtns	149.99%	0.00%	#######	#######	94.37%	#######	#######	#######	#######	168.90%	124.42%	155.52%	154.61%	172.21%	173.78%	172.87%	175.99%	169.23%	159.86%	175.22%	173.53%	73.34%	160.99%	93.74%	185.43%	234.09%	100.00%	101.86%	231.68%	214.71%	194.42%	189.98%	202.71%	199.92%	209.04%	220.29%	223.14%
Sheephole Mtns	150.63%	0.00%	#######	#######	93.38%	#######	#######	#######	#######	170.43%	124.05%	156.17%	155.44%	173.93%	175.59%	174.61%	177.87%	170.49%	160.64%	177.11%	175.34%	72.63%	161.84%	93.53%	187.68%	239.65%	96.72%	98.78%	236.93%	218.52%	196.76%	192.00%	205.19%	202.49%	212.32%	224.45%	227.57%
Sheephole Mtns	178.02%	0.00%	#######	#######	#######	#######	#######	#######	#######	208.66%	141.91%	186.31%	185.03%	214.35%	217.66%	215.71%	220.82%	208.68%	192.75%	220.32%	217.28%	76.34%	183.06%	102.89%	232.60%	329.29%	90.89%	94.22%	327.95%	291.88%	251.91%	242.27%	259.76%	261.77%	280.71%	304.40%	310.74%
Bullions Mtns	220.73%	0.00%	#######	#######	#######	#######	#######	#######	#######	272.55%	167.88%	230.03%	231.71%	283.12%	290.03%	285.59%	293.87%	266.00%	238.06%	295.15%	289.83%	80.54%	212.54%	112.24%	307.41%	518.60%	63.58%	76.01%	499.55%	409.76%	329.67%	310.61%	330.41%	343.24%	381.89%	432.09%	448.23%
Queen Mtn	151.02%	0.00%	#######	#######	94.56%	#######	#######	#######	#######	170.34%	124.97%	156.42%	155.73%	173.75%	175.36%	174.41%	177.56%	170.35%	160.72%	176.83%	175.12%	73.28%	161.96%	93.72%	187.11%	237.07%	100.64%	102.59%	234.11%	216.33%	195.40%	190.84%	203.47%	200.76%	210.20%	221.83%	224.91%
Little San Bernardino Mtns	154.31%	0.00%	#######	#######	95.89%	#######	#######	#######	#######	174.57%	127.24%	159.69%	159.21%	178.17%	179.89%	178.85%	182.11%	174.26%	164.10%	181.44%	179.67%	73.96%	164.78%	95.36%	191.79%	244.29%	104.81%	106.90%	241.04%	222.36%	200.31%	195.43%	208.41%	205.95%	215.94%	228.22%	231.40%
San Gorgonio Mtns	156.41%	0.00%	#######	#######	99.16%	#######	#######	#######	#######	175.37%	128.98%	157.57%	161.07%	178.88%	180.19%	179.06%	181.39%	170.19%	160.20%	181.43%	180.33%	76.18%	168.35%	100.60%	190.08%	231.53%	124.33%	127.97%	222.30%	205.00%	185.67%	181.74%	191.37%	188.32%	197.09%	207.59%	211.01%
San Jacinto Mtns	149.59%	0.00%	#######	#######	#######	#######	#######	#######	#######	157.43%	136.32%	150.25%	151.64%	158.75%	159.17%	158.81%	159.76%	155.65%	151.53%	159.62%	159.19%	97.87%	156.64%	119.42%	163.71%	177.44%	137.58%	138.65%	174.63%	168.96%	162.14%	160.82%	165.18%	163.20%	166.22%	169.75%	170.93%
Santa Rosa Mtns	141.23%	0.00%	#######	#######	#######	#######	#######	#######	#######	148.43%	128.77%	141.92%	143.14%	149.64%	149.98%	149.68%	150.59%	146.89%	143.15%	150.39%	150.00%	93.58%	149.11%	113.66%	154.53%	167.15%	127.28%	128.32%	164.52%	159.24%	152.94%	151.80%	156.07%	153.91%	156.67%	159.92%	161.04%
Orocopia Mtns	118.26%	0.00%	#######	#######	83.53%	#######	#######	96.29%	#######	127.89%	102.83%	121.85%	120.83%	129.44%	129.94%	129.70%	131.41%	128.91%	124.53%	130.57%	129.74%	69.46%	131.95%	84.60%	138.16%	159.51%	76.89%	78.07%	158.27%	150.95%	141.95%	140.50%	148.74%	144.60%	148.29%	153.03%	154.37%
W. Chocolate Mtns	123.90%	0.00%	#######	#######	88.62%	#######	#######	#######	#######	133.70%	108.43%	127.48%	126.49%	135.27%	135.82%	135.55%	137.25%	134.64%	130.15%	136.47%	135.63%	72.99%	136.25%	88.90%	143.70%	165.03%	86.91%	87.97%	163.89%	156.73%	147.78%	146.25%	154.26%	150.49%	154.19%	158.88%	160.15%
N. San Bernardino Mtns	165.87%	0.00%	#######	#######	#######	#######	#######	#######	#######	182.07%	139.38%	162.93%	169.95%	185.18%	185.97%	184.82%	185.99%	173.27%	164.09%	186.78%	186.47%	86.86%	178.13%	124.71%	192.58%	219.19%	149.93%	153.22%	208.46%	196.16%	181.33%	178.29%	185.50%	182.58%	189.40%	197.22%	199.65%
S. Bristol Mtns	143.16%	0.00%	#######	#######	74.63%	#######	#######	90.56%	#######	168.91%	95.96%	116.66%	149.63%	174.99%	176.32%	173.48%	177.19%	125.70%	115.23%	178.03%	178.45%	73.31%	163.64%	125.21%	188.17%	256.91%	513.56%	503.82%	210.02%	160.46%	122.50%	119.76%	140.52%	126.01%	138.06%	154.30%	158.47%
Rodman Mtns	35.01%	0.00%	4.61%	5.95%	-4.22%	6.40%	5.60%	4.56%	4.36%	4.02%	11.94%	55.23%	44.39%	31.71%	34.39%	40.08%	41.84%	67.39%	58.70%	32.96%	35.06%	40.01%	-9.65%	83.21%	85.80%	163.92%	229.67%	229.90%	97.23%	84.47%	76.31%	76.21%	93.51%	76.88%	80.61%	86.76%	89.17%
Unnamed 2	226.43%	0.00%	#######	#######	#######	#######	#######	#######	#######	279.61%	171.28%	231.80%	237.70%	290.67%	297.57%	292.75%	300.49%	266.75%	238.34%	302.69%	297.86%	82.33%	217.02%	115.84%	313.27%	513.78%	67.41%	93.24%	478.91%	394.38%	319.20%	301.66%	318.91%	329.37%	365.13%	410.64%	425.52%

Appendix O. Desert Bighorn Sheep Percent Change in Resistance Distances Across All 69 Populations (from Present to High Renewable Development Continued)

	Clipper Mtns	Marble Mtns	Old Woman Mtns	Sacramento Mtns	Dead Mtns	Chemuevi Mtns	Whipple Mtns	Turtle Mtns	Riverside Mtns	Big Maria Mtns	Little Maria Mtns	Iron Mtns	Coxcombe Mtns	Palen Mtns	McCoy Mtns	Chuckwalla Mtns	Eagle Mountains	Pinto Mtns	Sheephole Mtns	Sheephole Mtns	Bullions Mtns	Queen Mtn	Little San Bernardino Mtns	San Gorgonio Mtns	San Jacinto Mtns	Santa Rosa Mtns	Orocopia Mtns	W. Chocolate Mtns	N. San Bernardino Mtns	S. Bristol Mtns	Rodman Mtns	Unnamed 2
Clipper Mtns	0.00%																															
Marble Mtns	163.50%	0.00%																														
Old Woman Mtns	208.61%	196.78%	0.00%																													
Sacramento Mtns	211.56%	206.29%	251.74%	0.00%																												
Dead Mtns	98.79%	100.97%	106.96%	96.56%	0.00%																											
Chemuevi Mtns	142.41%	143.43%	129.73%	97.06%	113.79%	0.00%																										
Whipple Mtns	173.97%	174.05%	170.30%	169.72%	140.47%	195.30%	0.00%																									
Turtle Mtns	230.81%	226.57%	257.22%	233.94%	143.24%	143.88%	141.04%	0.00%																								
Riverside Mtns	194.77%	195.81%	194.22%	191.98%	163.73%	172.28%	165.90%	178.25%	0.00%																							
Big Maria Mtns	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%																						
Little Maria Mtns	215.77%	218.73%	222.79%	218.98%	165.57%	181.36%	188.16%	215.63%	231.02%	0.00%	0.00%																					
Iron Mtns	209.15%	212.45%	217.99%	214.80%	158.36%	176.28%	185.58%	214.63%	223.87%	0.00%	256.57%	0.00%																				
Coxcombe Mtns	348.35%	346.53%	425.61%	346.98%	209.20%	231.78%	233.00%	335.79%	216.79%	0.00%	145.51%	89.47%	0.00%																			
Palen Mtns	233.09%	248.84%	234.16%	229.67%	157.20%	173.07%	184.65%	223.35%	194.92%	0.00%	159.92%	127.99%	182.62%	0.00%																		
McCoy Mtns	217.13%	220.53%	225.20%	221.23%	164.84%	181.75%	189.76%	219.86%	227.64%	0.00%	260.98%	253.98%	124.87%	149.10%	0.00%																	
Chuckwalla Mtns	223.53%	226.11%	230.04%	226.27%	176.48%	191.48%	197.38%	224.61%	234.26%	0.00%	271.16%	248.39%	163.47%	176.22%	249.77%	0.00%																
Eagle Mountains	178.55%	185.25%	181.04%	185.06%	141.94%	157.86%	170.49%	187.85%	190.45%	0.00%	181.82%	160.72%	167.86%	103.15%	180.14%	194.02%	0.00%															
Pinto Mtns	243.49%	260.64%	245.27%	239.72%	162.34%	179.73%	191.76%	235.71%	203.21%	0.00%	186.87%	161.57%	211.62%	196.35%	180.69%	199.17%	63.25%	0.00%														
Sheephole Mtns	248.21%	267.08%	249.07%	242.54%	162.55%	179.59%	191.54%	237.01%	201.54%	0.00%	180.24%	154.00%	211.72%	183.43%	172.73%	193.34%	67.02%	55.76%	0.00%													
Sheephole Mtns	333.60%	375.57%	325.95%	298.50%	182.91%	198.22%	207.51%	279.57%	206.01%	0.00%	177.77%	152.05%	262.21%	77.94%	168.55%	190.33%	84.27%	89.79%	78.96%	0.00%												
Bullions Mtns	426.99%	514.21%	390.66%	345.89%	201.84%	211.38%	218.71%	311.39%	212.01%	0.00%	187.60%	163.12%	282.56%	98.96%	179.03%	198.75%	91.01%	102.56%	97.09%	99.69%	0.00%											
Queen Mtn	243.72%	261.91%	243.66%	238.60%	162.25%	178.56%	190.36%	233.19%	200.22%	0.00%	178.71%	153.50%	208.80%	150.89%	171.42%	191.66%	63.01%	26.39%	17.36%	87.93%	102.60%	0.00%										
Little San Bernardino Mtns	250.39%	269.36%	250.76%	244.32%	164.56%	181.19%	192.91%	238.73%	202.81%	0.00%	183.97%	158.59%	214.19%	169.71%	177.18%	196.48%	71.54%	14.51%	29.27%	91.24%	106.51%	-0.09%	0.00%									
San Gorgonio Mtns	214.96%	231.96%	207.64%	210.79%	155.43%	164.89%	176.08%	202.89%	182.18%	0.00%	149.19%	128.21%	182.20%	75.08%	141.15%	162.73%	61.79%	47.04%	46.17%	84.96%	109.02%	43.84%	49.49%	0.00%								
San Jacinto Mtns	174.80%	180.48%	172.42%	176.08%	150.81%	156.90%	164.35%	173.81%	170.95%	0.00%	148.29%	136.28%	161.86%	116.71%	143.72%	156.70%	97.32%	104.34%	105.92%	122.28%	132.94%	105.35%	#######	151.67%	0.00%							
Santa Rosa Mtns	165.19%	170.50%	162.95%	167.15%	143.86%	150.12%	157.95%	165.27%	165.50%	0.00%	141.44%	129.25%	153.30%	107.79%	136.72%	150.27%	90.17%	95.00%	96.43%	112.75%	122.54%	95.85%	#######	138.07%	65.70%	0.00%						
Orocopia Mtns	169.42%	176.46%	171.33%	176.65%	134.95%	150.89%	164.28%	179.19%	184.20%	0.00%	169.01%	146.63%	158.68%	84.55%	165.60%	182.67%	193.69%	38.28%	39.44%	66.72%	73.73%	36.04%	42.39%	46.88%	89.46%	82.08%	0.00%					
W. Chocolate Mtns	174.76%	181.53%	176.98%	181.49%	139.28%	155.08%	167.93%	184.14%	187.74%	0.00%	176.38%	154.97%	164.13%	97.04%	173.96%	189.09%	165.84%	57.11%	58.61%	78.52%	85.28%	54.83%	63.06%	56.97%	94.42%	87.20%	220.02%	0.00%				
N. San Bernardino Mtns	199.66%	211.78%	194.15%	198.86%	155.80%	162.94%	172.99%	193.00%	178.56%	0.00%	150.39%	133.83%	180.23%	97.79%	143.97%	161.72%	82.12%	81.95%	82.39%	113.06%	136.53%	80.50%	83.34%	69.70%	#######	#######	71.48%	78.53%	0.00%			
S. Bristol Mtns	196.53%	235.73%	227.01%	229.58%	119.91%	156.32%	183.73%	243.34%	203.32%	0.00%	232.75%	228.19%	361.92%	285.82%	235.71%	237.99%	204.82%	299.92%	309.39%	452.95%	674.77%	302.73%	#######	269.52%	#######	#######	197.15%	#######	#######	0.00%		
Rodman Mtns	99.45%	108.48%	110.75%	134.08%	93.97%	118.18%	142.34%	147.80%	166.42%	0.00%	161.49%	150.43%	207.49%	147.86%	159.35%	174.19%	128.49%	152.68%	153.42%	182.51%	228.39%	153.77%	#######	158.88%	#######	#######	119.53%	#######	#######	144.74%	0.00%	
Unnamed 2	389.27%	459.58%	355.89%	325.81%	198.56%	205.74%	213.68%	294.43%	208.11%	0.00%	183.38%	160.60%	266.25%	102.28%	175.28%	194.62%	92.35%	101.57%	98.02%	92.41%	51.70%	102.25%	#######	122.62%	#######	#######	76.60%	87.08%	#######	590.04%	#######	0.00%

Appendix P: Additional general recommendations for renewable energy development, urban development, and conservation planning.

The methodology developed by this project can be applied to environmental analyses of future urban and renewable energy development to integrate consideration of fragmentation, connectivity, and gene flow into the development process. General considerations to maintain ecological integrity in West Mojave and elsewhere include:

1. *Plan at a regional scale for cumulative impacts .* Although the National Environmental Policy Act and the California Environmental Quality Act require review of site-specific project impacts, the cumulative impacts of multiple projects to a region are rarely analyzed in detail. By first examining the impacts of development at a regional scale, land managers will be better able to avoid landscape-scale impacts on habitat connectivity, reduce barriers to movement, and maintain genetic viability for species of concern.

2. *Evaluate long time scales in planning horizons.* Climate change is anticipated to have significant impacts to species and habitats in ecosystems around the world. Long-range planning needs to account for how climate change will affect species movement patterns and habitat connectivity to assess probable future impacts of development.

   Additionally, ecological processes that depend on habitat connectivity, such as gene flow, can have significant time-lags. The consequences of genetically isolated population may not be realized for several generations. Planners and land managers should consider the longer time scales of ecological processes that affect species of concern

   Moreover, as California's population, economy, or per-capita energy demand continues to grow, and if California is to reach its goal of reducing carbon dioxide emissions to 80% below 1990 levels, demand for renewable resources is likely to intensify. Without appropriate planning, this may result in significant impacts to habitat continuity, species movement, and gene flow in the West Mojave.

3. *Work to incorporate ecological processes such as connectivity into environmental considerations during the development process.* Just as the cumulative, regional impacts are rarely analyzed in detail, impacts to ecological connectivity from habitat fragmentation are also rarely analyzed in detail.

4. *Anticipate potential "leakage" or rebound effects.* Limiting development in some areas may instead push it to another site and not actually stop the development, especially if demand is inelastic and there is a large supply of land (Ewers & Rodriguez, 2008). Anticipating these situations may help prevent accidental development in areas with even greater ecological value. This is particularly crucial when development on an ecologically poor section of public land is denied and inadvertently moved to an ecologically rich section of private land.

5. *Continue to investigate and support alternatives to large-scale renewable energy.* Every watt of energy saved through energy efficiency or generated through distributed renewable energy sources simultaneously reduces the need for fossil fuels and for large-scale renewable energy development in the Mojave. Greater energy efficiency or distributed energy generation may prove just as effective, and have a smaller or insignificant ecological impact compared to large-scale renewable energy development. In addition, current planning efforts do not identify enough in-state renewable energy sources to meet the highest levels of potential demand. If additional in-state capacity is not identified, the state might need to pursue additional out-of-state energy sources, distributed energy generation, or greater energy efficiency.

6. *Consider the Mojave's variation in ecological assessments.* The geology of California, including the base rock upon which its soils are built as well as the terrain topography, is diverse. This diversity creates similarly diverse habitats and species compositions. Compared to California, the basin-and-range mountains that cover much of Nevada has relatively little diversity in its base rock composition and topography and may thus offer an alternative location for renewable energy (Connie Vadheim, personal communication, October 2008).

7. *Incorporate connectivity into previous analyses*. Neither the Geothermal Programmatic Environmental Impact Statements (PEIS) nor the Wind PEIS explicitly examine ecological connectivity in detail or the impacts that such developments might have on gene flow or metapopulations. In the Geothermal PEIS, the effects of habitat fragmentation were considered to be “minor” without performing a formal connectivity analysis. As discussed previously in this report (Section 6.3.3.2), the Wind PEIS included a discussion of potential impacts to various ecological processes, habitat fragmentation, and alterations to animal behavior. However, the impacts were mainly attributed to construction, not operation and maintenance, and there was no formal analysis of connectivity. To better inform decisions that will permanently alter the natural landscape, planners could

incorporate methodology employed by this project to better understand impacts on connectivity and gene flow.

8. *Expand upon our research.* By incorporating additional species, more areas of concern could be highlighted. For an extended list of how , including plants such as the Joshua tree. More suggestions for directions that future research might take can be found below (Section 11.4).

9. *Account for impacts to connectivity in Best Management Practices for renewable energy generation.* The Renewable Energy Action Team is currently developing Best Management Practices (BMP) for renewable energy generation. These BMPs should include mitigation measures, such as:

   a. *Minimize dispersed development.* Compact development has a smaller disturbance zone and therefore less impact on connectivity (Theobald 1997). Co-locating large projects, or using a smaller number of large, space-efficient facilities could reduce the amount of transmission, roads, and other infrastructure needed between projects to minimize habitat fragmentation and impacts on habitat connectivity and gene flow.

   b. *Consider modifying project location or design to preserve undisturbed lands and other areas important for ecological processes.* Similarly, attempt to build on previously disturbed lands to minimize the impact to pristine habitat (Sutherland 2004). Most planning organizations, including RETI, recognize the value of siting renewable energy development on previously disturbed lands instead of pristine lands in order to minimize ecological impacts (RETI Stakeholder Steering Committee 2009). However, data on what land has been previously disturbed is lacking, and creating a dataset of previously disturbed habitat could help facilitate the use of such lands for development.

   c. *If development is unavoidable, ensure that the surrounding area – or any other areas important for connectivity – are shielded from further development.* Impacts from any one project on connectivity may not be great, but the cumulative impact from multiple developments may result in ecological collapse.

   d. *Eliminate unnecessary fencing.* Fencing creates an impenetrable barrier to movement for many species and drastically reduces the permeability of development for such movement.

e. *Minimize the number of roads.* Roads often involve grading and have significant impacts on ecological and hydrological processes. Roads can reduce biodiversity and mobility and increase the risk of invasion from exotic species (see Section 6.2). Paved roads have been shown to effectively suppress desert tortoise populations located within 400 meters (see Section 5.4.2

Appendix Q. Contact Information for Updated Data, Analyses, Reports, and Publications

The work contained herein represents the culmination of a two-year Masters Thesis Group Project. Several members of the project team will be pursuing additional work on this interesting and timely topic. For updated data, analyses, reports, and publications please contact:

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