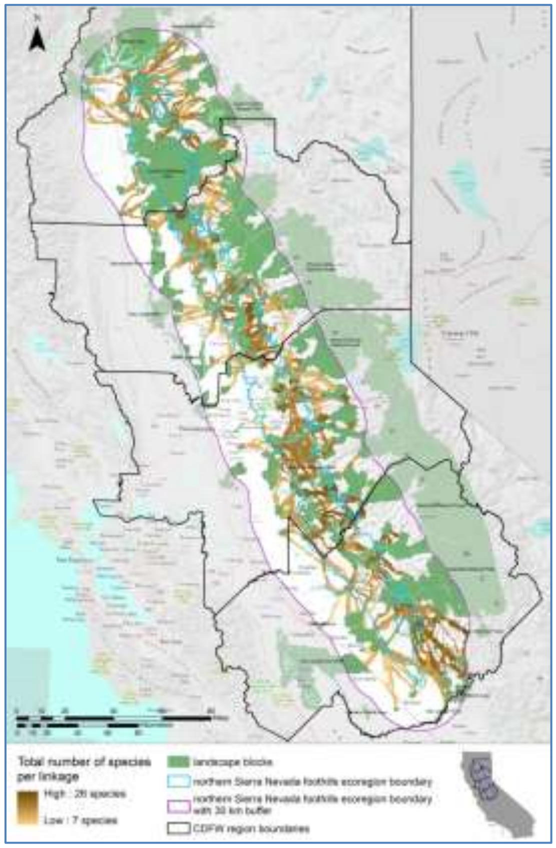
Wildlife connectivity across the northern Sierra Nevada foothills



Technical report to the California Wildlife Conservation Board on the northern Sierra Nevada foothills fine-scale connectivity analysis

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January 2015

Acknowledgments

We would like to thank the California Wildlife Conservation Board for funding; Canh Nguyen, David Wright, Stacy Heminway, Chris Curlis and Sara Holm of CDFW Region 2 and Sara Morrison and Charlotte Peters of CDFW Region 4 for providing species data and support; Levi Souza, Matt Meshiry, Marc Kenyon, Mary Sommer, Laura Patterson, Carie Battisone, Neil Clipperton, Caitlin Bean, and David Wright for reviewing our habitat models; Dan Applebee for input on parcel size in the urban mask; Dr. Lorraine Flint and Dr. Alan Flint of USGS for providing the downscaled climate data; Dr. Robert Hijmans of UC Davis for his technical help related to the 'dismo' R package; Todd Keeler-Wolf, Diana Hickson and Rosie Yacoub for vegetation data and input on land facets; Brian Brost and Jeff Jenness for technical help related to the land facets analysis; all attendees of our April 5, 2013 Conservation Partners meeting who provided input on Landscape Blocks; regional land trusts and CDFW Lands staff who provided Conservation Easement data; and Sophie Klenner and Sandra Summers of CDFW BDB for technical assistance. Images in this report are from the US Fish and Wildlife Service National Digital Library.

How to use this report

The purpose of this project was to build onto the statewide California Essential Habitat Connectivity (CEHC) work as recommended in the CEHC project report. Our project objectives were to take a fine-scale look at connectivity within the NSNF and between the NSNF and adjacent lands in the Central Valley and Sierra Nevada, using species-specific data to model connections between blocks of protected lands. The models identified important core habitat areas for focal species as well as least-cost-path wildlife corridors between these core areas. We also identified riparian and land facets corridors. Land facet corridors are areas of land with uniform topographic and geologic features that will interact with future climate to support species and species movement under future climate conditions. Our connectivity analysis incorporated species-specific habitat data, patch size and dispersal ability of 30 focal species to identify the best corridors for species to find habitat and move across the landscape. This analysis can help us to better understand what barriers to species movement are present in the landscape, where they are located, and will help us devise a strategy to maximize landscape connectivity for conservation and land use planning.

Species-specific information and analysis; results maps (habitat suitability models, core habitat patches, and least-cost corridors); and discussion of habitat suitability, connectivity and barriers for each species can be found in the focal species section of the report. Final maps for wildlife linkages, riparian corridors and land facet corridors can be found in the Results section of the report. The corresponding GIS shapefiles of the project results can be viewed online or downloaded from the CDFW BIOS website [http://www.dfg.ca.gov/biogeodata/bios/]. A summary of findings about connectivity and barriers throughout the foothills, as well as an analysis comparing the methodologies used in this project, can be found in the Discussion section of the report. Additional information on conducting a fine-scale habitat connectivity analysis can be found in our Guidance Document (https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=93018).

Contents

1 Executive Summary

Habitat loss and fragmentation are major threats to the biodiversity of California as urban development and infrastructure transforms the landscape to meet the growing human population needs of the state (FRAP 2010). These threats can impact wildlife in multiple ways including barriers to movement and gene flow, increased risk of mortality due to vehicular collisions or human activities, and increased risk of exposure to disease (Ordenana et al. 2010). Habitat fragmentation caused by urbanization can lead to the decline or even the local extinction of species with large home ranges, such as mountain lions, bobcats and coyotes (Crooks 2002). Connected landscapes are preferable to fragmented landscapes for maintaining wildlife populations and ecological processes (Beier and Noss 1998) and building a connected landscape through the identification and conservation of corridors may offer help in mitigating the impacts of habitat loss and fragmentation.

Wildlife connectivity and linkages are a key component of wildlife conservation. In 2008, the California Legislature added language (AB 2785) to the Fish and Game Code recognizing the importance of connectivity to the long-term viability of the state's biodiversity (FGC 1930c). Both the Fish and Game Code (FGC 1930d) and the State Wildlife Action Plan have identified fragmentation and lack of habitat connectivity as key stressors to California's wildlife. Furthermore, the 2009 California Climate Adaptation Strategy recognized that corridors that provide paths for movement between currently occupied habitat and habitat that will be suitable in the future under different climate scenarios are essential to facilitate the persistence of species in the face of climate change. The California Department of Fish and Wildlife (Department) has been charged with investigating, studying, and identifying those areas in the state that are most essential to habitat corridors and linkages (FGC 1930.5). The Wildlife Conservation Board funded this study, which was conducted in the Conservation Analysis Unit of the Department's Biogeographic Data Branch, to conduct a regional connectivity analysis using fine-scale vegetation data developed by the Department's Vegetation Classification and Mapping Program.

The northern Sierra Nevada foothills (NSNF) ecoregion was selected as the study area for this analysis because it represents an important movement corridor between the low elevations of the Central Valley and the mountains of the Sierra Nevada, and because of the availability of a fine-scale vegetation map with accurate land cover data for modeling. The NSNF encompasses a narrow band (~32 km wide) of low to mid-elevation habitat approximately 450 km long that runs from Shasta County to Madera County. Many species find habitat throughout the northern Sierra Nevada foothills (600+ species; CWHR 2008). The foothills provide key habitat areas for species such as mule deer that migrate seasonally between high elevations in the Sierras during the summer and lower elevations in the foothills during the winter. The oak woodlands in the foothills also provide an important food source (acorns) for many species ranging from birds, to rodents, to large mammals (CWHR 2008). We identified 238 "landscape blocks" in the study area, representing protected lands that provide core habitat areas for wildlife. The purpose of the study was to model linkages – the best habitats for wildlife movement - between these landscape blocks.

We used species-specific data in conjunction with fine-scale vegetation (habitat) data to develop habitat suitability models for 30 focal species representative of the wildlife of the study region, selected based on their sensitivity to habitat fragmentation. Habitat suitability model results were reviewed by Department species experts, and the results used to identify core habitat patches for each species. For nine of the most motile species ("passage species"), the data were then used to identify least-cost corridors linking core habitat patches between landscape blocks. For 21 "corridor dwellers", species that live in the corridor and may take several generations to move through a corridor, a patch analysis was used to identify "stepping stones" of habitat patches within dispersal distance of the species connecting landscape blocks. The habitat corridors and habitat patches for the 30 focal species were combined to build a linkage that would provide for wildlife movement between each pair of neighboring landscape blocks.

Our analysis identified 246 wildlife linkages connecting 198 landscape blocks, with each linkage providing habitat for at least seven and up to 26 focal species (mean=16). The total linkage area is 1,143,695.9 ha. Of this area, 13.9% are lands under permanent conservation protection (USGS GAP status 1, 2, or 3 or in conservation easement). The linkages range in elevation from 7 m to 2,379 m and cover many different vegetation types. For the total area of linkages, 27.4% were in oak woodland, 24.6% in grassland, 5.5% in chaparral, and 10.6% in mixed conifer.

In some parts of the foothills, there were many overlapping linkages identified. This indicates that natural habitat in these areas is still relatively continuous and species have many options when moving across the landscape. For conservation, this means that there are likely a variety of opportunities to maintain connectivity for wildlife. In other areas there was only a single corridor or no corridor identified between two neighboring blocks. This indicates that wildlife movement between the blocks may be impeded by barriers and opportunities for maintaining connectivity are likely limited. Restoration or other mitigation efforts may be required to achieve adequate connectivity between habitat patches when little natural connectivity is remaining. Linkages that cross highways and major roads may likewise require special attention to ensure that the linkage adequately functions to provide wildlife connectivity.

In addition to the wildlife linkages, we identified 280 riparian corridors throughout the study region. Riparian corridors are important for wildlife movement because they provide continuous swaths of cover, food, and water, and they may also provide the only remaining natural swaths of habitat through highly modified landscapes. The riparian corridors provided many east-west corridors, which complemented the wildlife linkages, the majority of which had a north-south orientation. Riparian corridors offer an important tool for conservation planning, representing areas that are important for wildlife and serve multiple ecological functions, although our analysis found they provide species habitat and connectivity for only a subset of species in the study area.

To address species movement under climate change, we also identified land facet corridors. Land facets are areas of the landscape with uniform topographic and geologic characteristics that can be used to predict areas of habitat that are expected to be suitable in future climates without relying on models of future temperature and precipitation, which have high uncertainty. We used a land facet analysis to identify 169 land facet corridors representing canyons, slopes, and ridges, connecting 94 landscape blocks.

A connected landscape is crucial for maintaining ecological processes and healthy wildlife populations over time. There are many factors that influence wildlife movement including ecological attributes of the landscape, physical attributes of the landscape, and species behavior (Van Vuren 1998). A natural landscape without man-made barriers provides the greatest freedom for species to maintain natural movement patterns and for ecological processes to continue unhindered, although physical barriers to movement also exist in natural landscapes. A connectivity analysis can help us to better understand what barriers are present in the landscape, where they are located, how they may affect species movement, and can help us devise a strategy to maximize landscape connectivity in the future. The habitat patch analysis provides a way to see where the important core habitat areas for each species are located in the landscape and how they are juxtaposed with conservation lands, as well as to identify isolated habitat patches or habitat patches likely to become isolated in the future. The least-cost path analysis provides a robust methodology for identifying how the core habitat areas within conservation lands can best be linked together to support wildlife populations and wildlife movement over time. The maps of core habitat patches and wildlife linkages, supplemented by maps of riparian corridors and land facets, can be used to address species-specific conservation needs as well as overall habitat connectivity in conservation planning.

Connectivity and Barriers in the Foothills

For the purposes of analysis, discussion, and representation on maps, we split the study area into four subsections from north to south based on the Department's Region boundaries and county boundaries.

The **NSNF Region 1 subsection** is the northernmost subsection of the study area and includes parts of Shasta, Tehama, and Plumas counties. The southwestern side of this study subsection has some agricultural and urban development from Corning to Red Bluff, in some places extending to the boundary of the foothills ecoregion. The northwestern side of this subsection includes the City of Redding and Lake Shasta, which pose barriers to movement to the north and west. Within the foothills and on the eastern side of the study area, natural habitat is fairly continuous and generally well-connected, although some naturally isolated habitat patches were found in the east. Much of the foothills area in Tehama County is covered by a single landscape block (Chilcoot Wilderness Area Block) which includes various conservation lands including the Tehama Wildlife Area, the Nature Conservancy's Dye Creek Preserve and Vina Plains Preserve, and parts of the Lassen National Forest. Several large landscape blocks are found on the east side of the study area including Lassen National Forest and Lassen National Park. Linkages providing habitat for the largest number of focal species are located on the eastern edge of the foothills between Lassen National Forest and the south fork of Battle Creek, as well as southeast of the town of Shingleton near the town of Manton. Wildlife linkages on the western side of this study subsection have the greatest number of major road crossings, including Highway 5, and State Routes 299 and 273.

The **NSNF Region 2 North subsection** ranges from Butte County south through Nevada, Yuba, and Sutter counties. The western side of this study subsection has extensive agricultural and urban development, in most places extending to the boundary of the foothills ecoregion, including the cities of Marysville, Yuba City, Gridley, Oroville, and Chico. Habitat patches on the western side of the study area were found to have limited connectivity with the foothills. The City of Oroville and adjacent Lake Oroville are significant barriers to wildlife movement that span the entire width of the foothills in Butte County. In addition, the cities of Grass Valley, Nevada City, and Paradise pose barriers to movement in the central and eastern foothills. On the eastern side of the study area, natural habitat is fairly continuous and generally well-connected, although extensive logging in the forests on the east side of the study area may impact habitat suitability. Several large landscape blocks are found on the east side of the study area including the Plumas and Tahoe National Forests. Wildlife linkages providing habitat for the largest number of focal species are located through the central foothills: between Big Chico Creek and the Plumas National Forest, and near the Spenceville Wildlife Area and Bear River. Wildlife linkages with the greatest number of road crossings are on the western side of the study area between the Sutter Buttes and Spenceville Wildlife Area, crossed by highways 99, 70, and 20; and a connection on the eastern side of the foothills near the town of Grass Valley that is crossed by highways 49, 20, and 174.

The **NSNF Region 2 South subsection** ranges from Placer County south through Calaveras County. The western side of the study subsection is highly developed, including the cities of Sacramento and Elk Grove, and adjacent agricultural areas. Habitat patches on the western side of the study area were found to have limited connectivity with the foothills. The cities of Sacramento, Roseville, Lincoln, Auburn, and surrounding cities along Highway I-80 represent a significant barrier to wildlife movement that extends from west to east across almost the entire study area. Outside of these urban areas, natural habitat within the foothills and on the eastern side of the study area is fairly continuous and generally well-connected. Several large landscape blocks are found on the east side of the study area including the El Dorado and Tahoe National Forests. Wildlife linkages providing habitat for the largest number of focal species are located through the central foothills, including from the Cosumnes River south to the Mokelumne River; between the Mokelumne River and the Antelope Valley Wildlife Area; and south from the Mokelumne River and Bear Mountains to New Melones Lake. Wildlife linkages with the greatest number of major road crossings are those to the north, east, and south of the greater Sacramento area, with road crossings of highways 80, 50, 49, 16, 88, 104, and 124.

The **NSNF Region 4 subsection** ranges from Tuolumne County south through Madera County, and into a small area of northern Fresno County. The cities of Merced and Madera are located in the western and southern side of this study subsection, and intensive agricultural development is found along the entire western side of the study area, in some places extending almost to the boundary of the foothills ecoregion. The western part of the foothills in this subregion has little land under conservation protection; very few landscape blocks were identified in the western foothills, and no landscape blocks were identified on the southern end of the foothills. Several landscape blocks were identified in the Central Valley on the western side of the study area, although habitat patches in these blocks had limited connectivity with the foothills due to surrounding agricultural and urban development. Natural habitat within the foothills and on the eastern side of the study area is fairly continuous and generally well-connected. Several large landscape blocks are found on the east side of the study area including Yosemite National Park and Stanislaus National Forest. Linkages providing habitat for the largest number of focal species are located in the eastern and southeastern part of the subregion as well as in the central foothills between New Melones Lake, the Red Hills, and the Stanislaus National Forest. Linkages with the greatest number of major road crossings include one on the western side that crosses highways 4, 120, and 132, and several on the southern end of the study area crossing highways 99, 49 and 41.

2 Introduction

2.1 Importance of wildlife connectivity

Habitat loss and fragmentation are major threats to the biodiversity of California as urban development and related infrastructure projects transform the landscape to meet the growing human population needs of the state (FRAP 2010). These threats can impact wildlife in multiple ways by creating barriers to movement and gene flow, and by increasing the risk of mortality due to vehicular collisions, human activities, and exposure to disease (Ordenana et al. 2010). Habitat fragmentation caused by urbanization can lead to the decline or even local extinction of many area sensitive species such as mountain lion, bobcats and coyotes (Crooks 2002). A connected landscape is preferable to a fragmented landscape (Beier and Noss 1998) and identifying and building a connected landscape with corridors may offer help in mitigating the impacts of habitat loss and fragmentation.

2.2 Importance to the Department

Wildlife connectivity and linkages are a key component of wildlife conservation. In 2008, the California Legislature added language (AB 2785) to the Fish and Game Code recognizing the importance of connectivity to the long-term viability of the state's biodiversity (FGC 1930c). Both the Fish and Game Code (FGC 1930d) and the State Wildlife Action Plan have identified fragmentation and lack of habitat connectivity as key stressors to California's wildlife. Furthermore, the 2009 California Climate Adaptation Strategy recognized that corridors that provide paths for movement between currently occupied habitat and habitat that will be suitable in the future under different climate scenarios are essential to facilitate the persistence of species in the face of climate change. The Department of Fish and Game (Department) has been charged with investigating, studying, and identifying those areas in the state that are most essential to habitat corridors and linkages (FGC 1930.5). The Legislature specified its intent that the Wildlife Conservation Board (WCB) should use various funds to work with the Department and support these efforts (FGC 1930.5b).

2.3 What's been done

Several projects have examined wildlife connectivity throughout California at different scales, from statewide projects such as the California Essential Habitat Connectivity Project and Missing Linkages Project, to regional projects such as the California Desert Connectivity Project, to local species-specific projects such as the work done by Epps et al. (2007) on desert bighorn sheep.

The *Missing Linkages: Restoring Connectivity to the California Landscape* project was developed by a group of land managers, planners, scientist and conservationist from across the state that met to identify the location of and threats to wildlife movement corridors in California at a conference in 2000 (Penrod et al. 2001). This project identified 232 linkages based on expert knowledge.

A decade later, the *California Essential Habitat Connectivity Project* (CEHC), commissioned by the California Department of Transportation (CalTrans) and California Department of Fish and Wildlife (Department), identified connectivity areas statewide based on the best available GIS data. This analysis provides a broad overview of remaining wildland areas (natural landscape blocks) and connectivity pathways between these blocks (essential connectivity areas), using transparent and repeatable modeling methods. The project was developed in collaboration with over 200 partners across the state. The final connectivity map depicts 850 Natural Landscape Blocks and 192 Essential Connectivity Areas based on the concept of ecological integrity (Davis et al. 2003, Davis et al. 2006, Spencer et al. 2010). The CEHC map products are broad scale and do not incorporate species-specific connectivity needs. The CEHC report recommends fine-scale regional analysis to identify important connectivity areas for use in local and regional conservation planning.

Examples of regional studies of connectivity in California include the South Coast Missing Linkages project, the California Desert Connectivity Project, Critical Linkages: Bay Area and Beyond, a San Joaquin Valley linkages project, and desert bighorn sheep fine-scale connectivity models. The South Coast Missing Linkages project has identified habitat and connectivity needs for southern California (Beier et al. 2006). This fine scale project encompassed 11 focal species based linkage designs (Penrod et al. 2003, Luke et al. 2004, Penrod et al. 2004a, Penrod et al. 2004b, Penrod et al. 2005b, a, c, d, 2006a, b, Penrod et al. 2006c, Penrod et al. 2008a, Penrod et al. 2008b, Penrod et al. 2012). The California Desert Connectivity Project evaluated connectivity needs across the deserts of California and developed fine scale focal species based linkage designs (Penrod et al. 2012). This project selected 44 focal species and identified 22 linkage planning areas (Penrod et al. 2012). The Critical Linkages: Bay Area and Beyond project identified areas vital for connectivity for the nine county Bay Area. This project selected 66 focal species and identified 14 linkage planning areas (Penrod et al. 2013). Huber et al. (2012) developed fine scale focal species based linkages in the San Joaquin Valley for four focal species. Epps et al. (2007) developed desert bighorn sheep fine scale connectivity models with genetic data for portions of the Mojave and Sonoran Desert ecoregions. These are just some examples of connectivity work across the state. One of the ecoregions not covered by previous projects is the Sierra Nevada foothills.

2.4 Importance of wildlife connectivity in the foothills

The northern Sierra Nevada foothills (NSNF) ecoregion encompasses a narrow band (~32 km wide) of low to mid-elevation habitat approximately 443 km long that runs from Shasta County to Madera County. The foothills ecoregion is oriented approximately parallel to the coastline, ~200 km inland, just east of the Central Valley and west of the Sierra Nevada mountains. The foothills ecoregion represents an important movement corridor between the low elevations of the Central Valley and the mountains of the Sierra Nevada. The foothills also provide key habitat areas for species such as mule deer that migrate seasonally between high elevations in the Sierra Nevada mountains during the summer and lower elevations in the foothills during the winter. The oak woodlands in the foothills also provide an important food source (acorns) for many species ranging from birds, to rodents, to large mammals (CWHR 2008). More than 600 species find habitat throughout the northern Sierra Nevada foothills (CWHR 2008), including 37 species that are State or Federally-listed as Endangered, Threatened or Rare (CNDDB 2014, Appendix A).

2.5 Goals and Objectives

The purpose of this project was to build onto the statewide California Essential Habitat Connectivity (CEHC) work as recommended in the CEHC project report. Our project objectives were to take a fine-scale look at connectivity within the NSNF and between the NSNF and adjacent lands in the Central Valley and Sierra Nevada, using species-specific data to model connections between blocks of protected lands. The models identified important core habitat areas for focal species as well as least-cost-path wildlife corridors between these core areas. We also identified riparian and land facets corridors. Land facet corridors are areas of land with uniform topographic and geologic features that will interact with future climate to support species and species movement under future climate conditions.

We followed these basic steps to accomplish the goals and objectives of the project:

1. Select focal species and lands to connect (landscape blocks).
2. Predict suitable habitat for each focal species using Maxent (statistical model) and BioView (expert opinion model).
3. Conduct literature review to identify habitat patch size, configuration and dispersal distance variables for each species and develop habitat patch analysis.
4. Perform corridor analysis to identify areas of high quality habitat that can function as connections between landscape blocks for passage species.
5. Perform a patch analysis to identify corridor needs for corridor dweller species.
6. Perform a linkage analysis that combines the results of the corridor and patch analysis to identify areas of connectivity for passage species and corridor dwellers.
7. Identify riparian corridors that connect landscape blocks.
8. Perform land facet corridor analysis to identify areas of topographic similarity that may provide resilience to climate change.
9. Compare the three corridor types to evaluate best habitat coverage and movement areas.

3 Methods

3.1 Study Area

The study area encompasses the NSNF and a 30 km buffer around the ecoregion (Figure 1). The 30 km buffer was included to incorporate movement between the low elevation Central Valley and higher elevation of the Sierra Nevada mountains. The elevation for the study area ranges from 0 - 3,133 m, with a mean elevation of 545 m. The majority of vegetation in the study area is a matrix of grassland (20.7%), mixed conifer (15.8%) oak woodland (15.5 %) and agriculture (16.3%; source vege15). Of the 1,032,353 total ha in the NSNF ecoregion, 171,182 ha (16 %) are in permanent protection, owned and managed by the US Bureau of Land Management, US Forest Service, California Department of Fish and Wildlife, and 55 other federal, state and local agencies; counties; cities; conservation NGOs and land trusts. An additional 30,000+ ha (3%) are under conservation easement (as mapped in the National Conservation Easement Database).

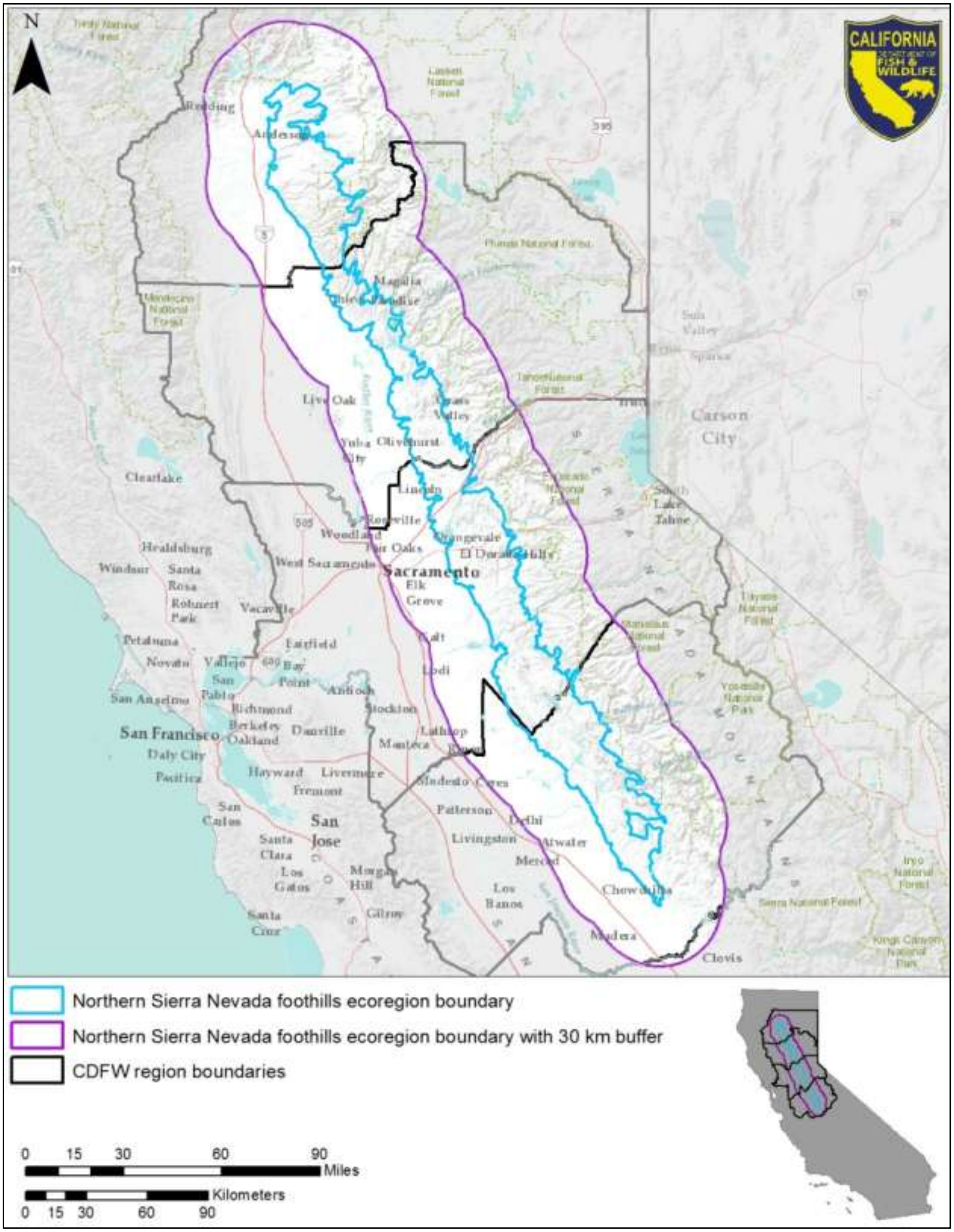

Figure 1: Map of the northern Sierra Nevada foothills ecoregion boundary with 30 km buffer.

3.2 Focal Species

Focal species habitat data provide the underpinning of each linkage. Beier et al. (2009) suggests selecting a diverse group of focal species to design linkages. We selected our focal species from a list of terrestrial vertebrate species known to occur in our study area, based on the California Wildlife Habitat Relationships (CWHR) system (http://www.dfg.ca.gov/biogeodata/cwhr/).

We developed selection criteria and ranked each species according to the criteria. Next we evaluated the species to identify those that would use the corridor to move through (**passage species**) and that will live in the corridor (**corridor dwellers**). Corridor dwellers are those species that will live in the corridor and that may take multiple generations to move through the corridor.

The criteria for selecting focal species were based on movement and habitat requirements: we prioritized species with movement as a key component of their life history as well as species whose habitat and movement needs encompassed those of multiple species (Table 1). Species that met the selection criteria were then stratified across taxonomic groups to represent the diversity of habitat requirements and movement needs across the ecoregion. We solicited expert opinion from the Department's species experts and region office biologists to select a final list of 9 passage species and 21 corridor dwellers for analysis (Table 2). This collaboration with species experts was helpful in several ways: species experts helped to identify data sources and biogeographic information such as home range, patch size and dispersal distance for each focal species, and later also reviewed habitat and connectivity models.

Table 1. Focal species selection criteria and ranking.

1	Area-sensitive: species that occur in lower density but require large areas
2	Barrier-sensitive: species that are specifically sensitive to road development
3	Umbrella: species that are representative of a trophic group/guild, related species, rare species, mobility class, key ecological process or other collection of species.
4	Dispersal-limited: species that require seasonal migration (fine scale movement)
5	Habitat specialist: species that are highly sensitive to habitat loss or fragmentation
6	Listed status: species of greater conservation need based on conservation status rankings

Table 2. List of focal species used in the northern Sierra Nevada foothills fine-scale wildlife connectivity analysis.

Taxonomic group	Scientific Name	Common Name	Corridor dweller	Passage species
amphibian	*Aneides lugubris*	ARBOREAL SALAMANDER	X	
	Rana boylii	FOOTHILL YELLOW-LEGGED FROG	X	
	Hydromantes brunus	LIMESTONE SALAMANDER	X	
bat	*Antrozous pallidus*	PALLID BAT	X	
bird	*Melanerpes formicivorus*	ACORN WOODPECKER	X	
	Callipepla californica	CALIFORNIA QUAIL	X	
	Toxostoma redivivum	CALIFORNIA THRASHER	X	
	Accipiter cooperii	COOPER'S HAWK	X	
	Chondestes grammacus	LARK SPARROW	X	
	Oreotyx pictus	MOUNTAIN QUAIL	X	
	Glaucidium gnoma	NORTHERN PYGMY OWL	X	
	Pipilo maculatus	SPOTTED TOWHEE	X	
	Aix sponsa	WOOD DUCK	X	
	Pica nuttalli	YELLOW BILLED MAGPIE	X	
carnivore	*Ursus americanus*	BLACK BEAR		X
	Lynx rufus	BOBCAT		X
	Urocyon cinereoargenteus	GRAY FOX		X
	Puma concolor	MOUNTAIN LION		X
ungulate	*Odocoileus hemionus*	MULE DEER		X
lagomorph	*Lepus californicus*	BLACK-TAILED JACKRABBIT		X
reptile	*Phrynosoma coronatum*	COAST HORNED LIZARD	X	
	Pituophis catenifer	GOPHER SNAKE	X	
	Coluber constrictor	RACER	X	
	Elgaria multicarinata	SOUTHERN ALLIGATOR LIZARD	X	
	Actinemys marmorata	WESTERN POND TURTLE		X
rodent	*Spermophilus beecheyi*	CALIFORNIA GROUND SQUIRREL	X	
	Dipodomys californicus	CALIFORNIA KANGAROO RAT	X	
	Neotoma fuscipes	DUSKY-FOOTED WOODRAT		X
	Dipodomys heermanni	HEERMANN'S KANGAROO RAT	X	
	Sciurus griseus	WESTERN GRAY SQUIRREL		X

3.3 Species location data and Environmental Variables

Species location data were compiled from multiple sources: two online museum collections, Global Biodiversity information facility (GBIF; http://www.gbif.org) and Arctos (http://arctos.database.museum/home.cfm); and the Department datasets from regional offices, the Wildlife Branch and the California Natural Diversity Database (CNDDB). Additional bird data were provided by Point Blue Conservation Science, formerly PRBO. The location points were inspected for consistency with known species range and duplicate points were removed. The species location data were split 70/30 for running and testing model performance within Maxent.

Climate variables, elevation, distance to water, and vegetation were used as environmental variables (Table 3). We conducted a correlation analysis using the 'Band Collection Statistics' tool in ArcGIS and removed one of the highly correlated variables in situations where two predictors are highly correlated ($r>0.7$).

Climate Variables: PRISM (Parameter-elevation Regression on Independent Slopes Model) monthly climate normals for the period between 1981 and 2010 were used as the source of the climate variables. The 800 meter climate normals were downscaled to 270 meter by Alan Flint and Lorrie Flint of USGS. Nineteen bioclimatic variables were then generated out of the monthly climate normals using an AML code written by Dr. Robert Hijmans of UC Davis. We used only 11 bioclimatic variables out of the 19 bioclimatic variables based on correlation analysis and also based on other ecological and biological considerations (Table 2). After an exploratory analysis of models using different combinations of climate variables, and in an effort to limit the number of variables used to reduce model overfitting, four bioclim variables were chosen for use in the final models: annual mean temperature (bio1), temperature seasonality (bio4), annual precipitation (bio12) and precipitation seasonality (bio15).

Elevation: Elevation data at 270 m spatial resolution was obtained from Alan and Lorrie Flint of USGS. The original source of the data is 30 m NED (National Elevation Dataset) of USGS which is a seamless elevation dataset for the conterminous United States. We considered slope and aspect as additional topography derived variables, but determined they were not ecologically important drivers of the distributions of our focal species. For this reason, we did not include slope or aspect.

Distance to Water: The distance to water layer represented distance to the nearest mapped perennial water source including perennial streams, rivers, lakes, and springs. It was generated using multiple datasets that map the location of perennial water sources including the NHD (National Hydrography Dataset) for state of California, wetland, riparian, lake and spring data as primary sources. First, a perennial streams dataset was created (see Appendix B for a full description of the processing steps). The resulting perennial streams dataset was then merged with the wetland, riparian, and springs data extracted from the project vegetation map, the Department's Vegetation Classification and Mapping program's (VegCAMP) vegetation maps, and the Department's Lake GIS dataset. The final merged dataset represented perennial water sources in California. This datasets was then used to create a raster measuring the distance of each cell to the nearest perennial water source.

Vegetation: We used the northern Sierra Nevada Foothills (Menke et al. 2011) and Eastern Central Valley (CDFW and GIC 2013) fine-scale vegetation maps developed by VegCamp. For areas outside the foothills and eastern central valley we used land cover data compiled by California Department of Forestry and Fire Protection (CDF) Fire and Resource Assessment Program (FRAP) in 2006, representing data for the period between 1997 and 2002. FRAP compiled the "best available" land cover data into a single data layer, to support the various analyses required for the Forest and Rangeland Assessment, a legislatively mandated function. The land cover data provided a crosswalk to 13 and 65 CWHR (California Wildlife Habitat Relationships) habitat types. Because the total extent of each class influences the output in Maxent when using a categorical variable, we reclassified the vegetation layer to 15 classes with relatively even area across the landscape for use in the model. We also generated vegetation layers for percent conifer habitat, percent grassland, percent hardwood habitat, and percent shrubland per grid cell to represent vegetation as continuous variables. To do this we reclassified the 30 m land cover data into the four 4 vegetation classes and calculated the percent of each land cover class per final 270 m grid cell.

Geology: We used the 2010 edition of the Geologic Map of California geodatabase (Jennings et al. 2010) to select import geologic features for Limestone salamander. We selected Mesozoic Metalvolcanic Rocks, Mesozoic Plutonic Rocks, Mesozoic Sedimentary and Metasedimentary Rocks, and Paleozoic Sedimentary and Metasedimentary Rocks features because they represented the species location points.

Table 1. Name and description of the environmental variables used in the habitat suitability models.

Variable	Variable Name	Description and Biological Interpretation
bio01	Annual Mean Temperature	The annual mean temperature approximates the total energy inputs for an ecosystem
bio02	Annual Mean Diurnal Range	The mean of the monthly temperature ranges (monthly maximum minus monthly minimum). It can help provide information pertaining to the relevance of temperature fluctuations for species distribution
bio03	Isothermality	It quantifies how large the day-to-night temperature oscillates relative to other summer-to-winter (annual) oscillations. A species distribution may be influenced by larger or smaller temperature fluctuations within a month relative to the year and this predictor is useful for ascertaining such information
bio04	Temperature Seasonality	The amount of temperature variation over a given year based on standard deviation of monthly temperature averages. It is a measure of temperature change over the course of the year. The larger the standard deviation the greater variability of temperature
bio05	Maximum Temperature of Warmest Month	This is calculated by selecting the maximum temperature value across all months within a given year. It ascertains whether the species distributions are affected by warm temperature anomalies throughout the year.
bio06	Minimum Temperature of Coldest Month	This is calculated by selecting the minimum temperature value across all months within a given year. It ascertains whether the species distributions are affected by cold temperature anomalies throughout the year
bio12	Annual Precipitation	This is the sum of all total monthly precipitation. It helps to ascertain the importance of water availability (total water inputs) to species distributions
bio15	Precipitation Seasonality (CV)	This is the measure of the variation in monthly precipitation totals over the course of the year. It is calculated as the ratio of the standard deviation of the monthly total precipitation to the mean monthly total precipitation and expressed as a percentage. Can be useful if the species distribution is affected by precipitation variability.
bio16	Precipitation of Wettest Quarter	This quarterly index approximates total precipitation that prevails during the wettest quarter. It can be useful for examining how total precipitation during the wettest three months may affect species seasonal distributions
bio17	Precipitation of Driest Quarter	This quarterly index approximates total precipitation that prevails during the driest quarter. It can be useful for examining how total precipitation during the driest three months may affect species seasonal distributions
bio18	Precipitation of Warmest Quarter	This quarterly index approximates total precipitation that prevails during the warmest quarter. It can be useful for examining how total precipitation during the warmest three months may affect species seasonal distributions
distTowater	Distance to water	It measures distance to the nearest water point (streams, rivers, lakes, wetland or riparian area)
Elev	Elevation	Elevation is the height point of a location relative to sea level
pctconifer	Percent conifer	Percent of pixel mapped as conifer
pctgrass	Percent grass	Percent of pixel mapped as grassland
pcthrdwd	Percent hardwood	Percent of pixel mapped as hardwood
pctshrub	Percent shrub	Percent of pixel mapped as shrubland
pctwetland	Percent “wet”	Percent of pixel mapped as habitat type with surface water present
Vege13	Vegetation type	Vegetation type represented with 13 CWHR categories
Vege15	Vegetation type	Vegetation type represented with 15 classes
Vege65	Vegetation type	Vegetation type represented with 65 CWHR categories
Geology	Geologic features	Geologic features selected for Limestone Salamander

3.4 Landscape Blocks

Landscape blocks are the areas the corridors will connect. Landscape blocks can be defined many different ways depending on the goals of the study. Beier et al. (2011) suggest seven ways to define landscape blocks: expert opinion mapped areas; areas of high ecological integrity; all or a subset of protected areas; areas that meet quantitative conservation targets using optimization algorithms; previously developed conservation maps; maps of modeled or know habitat for a suite of species; or preliminary natural landscape blocks modified by highways or other linear barriers. For the NSNF we based our landscape blocks on protected lands managed primarily for biodiversity conservation, including 1) USGS GAP Analysis conservation status designations GAP 1 and 2 (see Table 4 for GAP status definitions); 2) lands under conservation easement; and 3) GAP 3 lands that intersect with CEHC natural landscape blocks (blocks of land >2,000 acres with high ecological integrity). This represented protected lands with high habitat value that were expected to maintain this habitat value and conservation status in the foreseeable future. After compiling a draft map of landscape blocks based on our criteria, we held a Conservation Partners meeting on April 5, 2013 to acquire input from stakeholders and local experts including local, regional, and state government land management agencies, land trusts, non-profits, and ecologists and species experts. We split our landscape blocks by major rivers and roads to identify barriers within blocks.

Table 4. Definition of lands selected for landscape blocks.

Acronym	Definition of land status
GAP 1*	An area of permanent protection from conversion of natural land cover and a mandated management plan to maintain a natural state and disturbance events.
GAP 2*	An area of permanent protection from conversion of natural land cover and a mandated management plan to maintain a primarily natural state, but may receive uses that degrade the quality of existing natural communities, including suppression of natural disturbance.
GAP 3*	Multiple use public lands. An area of permanent protection from conversion of natural land cover for most of the area, but subject to extractive uses of either a broad, low intensity type, i.e. logging, or localized intense type, i.e. mining; protection to federally listed species throughout the area.
NCED	Privately owned conservation easement lands from the National Conservation Easement Database, which represents approximately 60% of the conservation easements in California. Data are from land trusts and public agencies. Conservation easements are legal agreements voluntarily entered into between landowners and conservation entities (agencies or land trusts) for the express purpose of protecting certain societal values such as open space or vital wildlife habitats.

*USGS GAP Analysis program protected areas conservation status code (http://gapanalysis.usgs.gov/padus/data/)

3.5 Habitat models

For each focal species we developed two types of models to predict suitable habitat across the study area: a statistical Maxent model and an expert opinion vegetation model (CWHR BioView). We selected

Maxent (Phillips et al. 2006) because it is one of the well-performing species distribution models available and it is also able to handle presence-only species data. We used species location data, background points, and the environmental variables to predict habitat suitability. Background points (10,000 for each species) were randomly generated using the 'randomPoints' function in 'dismo' package (Hijmans et al. 2011). Due to the relatively large number of sample points for four bird species (acorn woodpecker, California quail, mountain quail, and spotted towhee), we used 30,000 background points for these four species. We implemented Maxent in R using the 'dismo' package (Hijmans et al. 2011). The models were developed at 270 m spatial resolution with five replications using 10-fold cross-validation as a method of sample evaluation. Cross-validation involves the partitioning of the sample data into *n* subsets and fitting the models to *n-1* subsets and testing the model on the one subset that is not used in fitting the model.

We developed several models for each species using different sets of environmental variables, or scenarios, as described below. The different scenarios were used to compare models with and without bioclimatic variables, and with categorical vs. continuous vegetation variables. Species experts reviewed the models for each species and provided input on variable selection and how well the model output matched the known distribution of the species. Based on expert input, additional variables, such as geology and percent wetland, were added for several species.

Scenario5 (categorical vegetation with climate): Four bioclimatic variables, elevation, distance to water, and vegetation were used to predict habitat suitability. The vegetation layer in this scenario was defined by 15 vegetation classes. The climatic variables were: bio01 (Annual Mean Temperature), bio04 (Temperature Seasonality), bio12 (Annual Precipitation), and bio15 (Precipitation Seasonality).

Scenario6 (categorical vegetation without climate): Elevation, distance to water, and vegetation were used to predict habitat suitability. The vegetation layer in this scenario was defined by 15 vegetation classes. All climate variables were excluded in order to see the effects of the remaining variables on model outputs.

Scenario7 (continuous vegetation without climate): Elevation, distance to water, and vegetation were used to predict habitat suitability. The vegetation data in this scenario was represented by four continuous vegetation datasets (percent conifer, percent grassland, percent hardwood, and percent shrubs). All climate variables were excluded in order to see the effects of the remaining variables on model outputs.

Scenario9 (continuous vegetation with climate): Four bioclimatic variables, elevation, distance to water, and vegetation were used to predict habitat suitability. The vegetation data in this scenario was represented by four continuous vegetation datasets (percent conifer, percent grassland, percent hardwood, and percent shrubs). The four climatic variables were: bio01 (Annual Mean Temperature), bio04 (Temperature Seasonality), bio12 (Annual Precipitation), and bio15 (Precipitation Seasonality).

Scenario5w (categorical vegetation, with wetland, with climate): Four bioclimatic variables, elevation, percent "wet", and vegetation were used to predict habitat suitability. Percent "wet" was added as an additional variable, created as a continuous grid to represent percent of the pixel where surface water would be present. The vegetation layer in this scenario was defined by 15 vegetation classes. The climatic variables were: bio01 (Annual Mean Temperature), bio04 (Temperature Seasonality), bio12 (Annual Precipitation), and bio15 (Precipitation Seasonality).

Scenario6w (categorical vegetation, with wetland, without climate): In this scenario, elevation, percent "wet", and vegetation were used to predict habitat suitability. Percent "wet" was added as an additional variable, created as a continuous grid to represent percent of the pixel where surface water would be present. The vegetation layer in this scenario was defined by 15 vegetation classes. All climate variables were excluded in order to see the effects of the remaining variables on model outputs.

Scenario7w (continuous vegetation, with wetland, without climate): Elevation and vegetation were used to predict habitat suitability. The vegetation data in this scenario was represented by five continuous vegetation datasets (percent "wet", percent conifer, percent grassland, percent hardwood, and percent shrubs). All climate variables were excluded in order to see the effects of the remaining variables on model outputs.

Scenario9w (continuous vegetation, with wetland, with climate): Four bioclimatic variables, elevation, and vegetation were used to predict habitat suitability. The vegetation data in this scenario was represented by five continuous vegetation datasets (percent "wet", percent conifer, percent grassland, percent hardwood, and percent shrubs). The four climatic variables were: bio01 (Annual Mean Temperature), bio04 (Temperature Seasonality), bio12 (Annual Precipitation), and bio15 (Precipitation Seasonality).

Scenario7g (continuous vegetation, with geology, without climate): In this scenario, elevation, distance to water, geology, and vegetation were used to predict habitat suitability. The vegetation data in this scenario was represented by four continuous vegetation datasets (percent conifer, percent grassland, percent hardwood, and percent shrubs). All climate variables were excluded in order to see the effects of the remaining variables on model outputs.

Scenario9g (continuous vegetation, with geology, with climate): In this scenario, four bioclimatic variables, elevation, distance to water, geology, and vegetation were used to predict habitat suitability. The vegetation data in this scenario was represented by four continuous vegetation datasets (percent conifer, percent grassland, percent hardwood, and percent shrubs). The four climatic variables were: bio01 (Annual Mean Temperature), bio04 (Temperature Seasonality), bio12 (Annual Precipitation), and bio15 (Precipitation Seasonality).

3.6 Model evaluation, threshold selection and data normalization

We evaluated model performance in R using the model evaluation metric AUC (area under the curve) using the 'PresenceAbsence' package in R (Freeman and Moisen 2008). For this evaluation method, AUC has been changed to accommodate for presence only data by using presence versus random rather than presence and absence (Phillips et al. 2006). Traditionally the Receiver Operating Characteristic (ROC) curve was used to evaluate the accuracy of the model and each variable's predictive power (Hanley and McNeil 1982). The ROC curve represents the relationship between the percentage of presences correctly predicted (sensitivity) and 1 minus the percentage of the absences correctly predicted (specificity). The area under the curve (AUC) measures the ability of the model to classify correctly a species as present or absent. AUC values can be interpreted as the probability that, when a site with the species present and a site with the species absent are drawn at random, the former will have a higher predicted value than the latter. For use with presence only data the AUC measures presence versus random background. A SDM can then make predictions for both a sample of presence and background points and a sample of background pixels (background pixels chosen uniformly at random; Phillips et al. 2006). Although the use of AUC test statistic has received criticism in recent years (Lobo et al. 2008), it is still viewed as an important metric when evaluating predictive performance (Elith and Graham 2009, Franklin 2009).

The 'PresenceAbsence' package in R (Freeman and Moisen 2008) also computes threshold values using several accuracy metrics to translate predicted probability maps into binary suitable and unsuitable habitats (Table 5). The species location points used in this project have two caveats: (i) they are presence only (with no species absence points available) and (ii) the samples are compiled from different data sources making it difficult to know the true observed prevalence (see for a detailed information on accuracy metrics Fielding and Bell 1997). For these reasons, we excluded threshold calculation methods that relied mainly on observed prevalence and sensitivity (which measures the proportion of observed absences predicted as true absences) and we selected the method known by the name 'MeanProb' which is a threshold set based on the mean predicted probability of species occurrences (Method 7 in Table 5).

The Maxent output are raster as multiband 'tif' format with one band for each replication. We averaged the five replicated maps and created a mean map for each species. We then used the threshold value to exclude areas with low probability and then normalized the data to range from 0-100. We then classified the raster into three bins of suitability, low suitability values of the threshold-50, medium suitability values of 51-75 and high suitability values of 76-100.

Table 5. Methods used in 'PresenceAbsence' package to calculate threshold values (from (Freeman and Moisen 2008).

	Methods	**Description**
1	Sens=Spec	Threshold where sensitivity equals specificity. It is a threshold where positive observations are just as likely to be wrong as negative observations.
2	MaxSens+Spec	Threshold that maximizes sum of sensitivity and specificity. This threshold minimizes the mean of error rates for positive and negative observations.
3	MaxKappa	Threshold that maximizes Kappa - where Kappa makes full use of the information in the confusion matrix to assess the improvement over chance prediction
4	MaxPCC	Threshold that maximizes PCC (percent correctly classified). This threshold becomes highly problematic for species with low prevalence.
5	PredPrev=Obs	Threshold where predicted prevalence equals observed prevalence. It uses the default prevalence in the data and it is not good if the observed prevalence is not truly known.
6	ObsPrev	Threshold set to observed prevalence. This threshold uses simply the observed prevalence in the data and it is not good if observed prevalence is not known *a priori*.
7	MeanProb	Threshold set to mean predicted probability. This method sets the threshold based on the mean probability of occurrence from the model results.
8	MinROCdist	Threshold where ROC curve makes closest approach to (0,1). This threshold minimizes the distance between ROC plot and the upper left corner of the unit square.
9	ReqSens	Highest threshold where sensitivity meets user defined requirement. The default is 0.85 which sets the model must miss no more than 15% of the points where the species is observed to be present.
10	ReqSpec	Lowest threshold where specificity meets user defined requirement. The default is 0.85 which sets the model miss no more than 15% of the points where the species is observed to be absent

3.7 Habitat patch analysis

The habitat patch analysis was used to identify all suitable habitat patches for each focal species across the study area, and all suitable habitat was denoted as a population patch, a breeding patch, or less than a patch. The SDM output, threshold value, species home range size and maximum dispersal distance are the basis for the patch analysis. Species home range size and dispersal distance were taken from the literature or expert opinion. Areas of contiguous suitable habitat larger than 25 times the recorded average home range size was recorded as a **population patch**. Population patches can sustain at least 50 individuals and may be capable of supporting the species for several decades. Areas of contiguous suitable habitat as least 2 times the minimum recorded home range but less than the population patch were identified as **breeding patches**. Breeding patches can support at least one breeding pair and are useful to the species if the patch can be linked via dispersal to other patches or core areas.

3.8 Least-cost corridor analysis

We followed the least-cost corridor techniques described by Beier et al. (2007) to identify a least-cost corridor, or the best potential route, for each species between each set of neighboring landscape blocks. The datasets needed for a least-cost corridor analysis are a resistance raster, core habitat patches, and landscape blocks. The resistance raster is the inverse of the SDM output, based on the assumption that cost for movement approximates the inverse of habitat suitability. We identified core habitat patches within the landscape blocks (population and breeding patches), and modeled the connections between these core habitat patches in neighboring blocks. In many landscape blocks there were multiple core habitat patches for a given species. We developed a least-cost corridor for each possible core habitat patch and used a rule-set to select the best individual species corridor between the two landscape blocks.

We developed the following rule-set to answer these questions:

1. Is the corridor continuous after urban mask is applied?
2. Does corridor provide sufficient habitat? Within species dispersal range?
3. Does expanding the corridor incorporate more habitat to meet species needs?

The least-cost corridor model identifies the least-cost corridor between any two patches, but does not evaluate whether all conditions to make the corridor functional are met, such as sufficient habitat patches within the dispersal distance of the species. It also does not evaluate whether there are barriers or other risks that could impede movement in the corridor. We evaluated each corridor to ensure it was ecologically functional.

We removed urban areas and areas of unsuitable/non-restorable habitat from the corridors and then inspected each corridor to make sure it was continuous. We examined the amount of predicted suitable habitat in each corridor, and measured the distance between habitat patches within each corridor to make sure they were within the maximum dispersal distance for that focal species. If the corridors did not meet these rules then habitat patches on the border of the corridor were added to meet the selection requirements, or the corridor was considered non-functional and deleted.

Once the final set of corridors was determined for each species, the corridors for the nine species were combined to generate a least-cost union. The least-cost union is a merge of the individual species corridors and identified the best swath of habitat available for focal species to move from one landscape block to another.

3.9 Linkages

The linkages incorporate data and information for all the focal species including corridor dwellers by building onto the least-cost union. From the least-cost union, habitat areas for corridor dwellers were added and redundant corridor were removed. First we identified all habitat patches within the corridor union and measured distance between each patch to make sure it was within the maximum dispersal distance for that corridor dweller; when needed, habitat near the corridor edge was added to meet the species dispersal needs. This analysis identified multiple swaths of habitat that species have the potential to reside in or move through. Redundant corridors were deleted to provide cleaner linkage areas.

To ensure that ecological processes were protected in each linkage, we imposed an average minimum width of 1 km for linkages. The minimum width of a linkage should be based on the needs of species that might inhabit the corridor rather than pass through, or may be based on home range size of the focal species (Beier et al. 2008). In areas where the linkage is less than the minimum width, Penrod et al. (2012) recommend adding natural habitats to either side of the union, and if no natural habitats are available, adding agricultural lands because they have the potential to be restored. Two km is suggested by several studies as a suitable minimum width (Beier et al. 2006, Brost 2010); however, due to the fine scale of our analysis, we imposed a 1 km minimum width.

3.10 Riparian corridors

We defined riparian corridors as the length of any stream with riparian vegetation mapped along at least part of the stream corridor. We used a perennial stream dataset derived from National Hydrography Dataset and Department Streams layer (see Appendix B) for state of California. We then extracted areas mapped as riparian vegetation in our project vegetation maps (2011 Northern Sierra Nevada Foothills and 2013 Eastern Central Valley VegCamp maps; FRAP multisource landcover for all other areas), and intersected these with the streams dataset to identify streams with mapped riparian vegetation. We added a 500 m buffer to each side of the stream to depict the riparian corridor.

3.11 Land facet corridors

We used land facets to model corridors that may be used for species movement with climate change. Land facets are formally defined as recurring landscape units with uniform topographic and soil attributes. Land facets focus on physical landscape units, such as slopes, ridges, and canyons, which will remain static over time even as the climate changes (Beier and Brost 2010). One of the methods often used to plan for the impending climate change effect on biodiversity is to design reserves and linkages using climate envelope models projected into future temperature and precipitation scenarios based on predicted emission scenarios. However, there is uncertainty associated with the emission scenarios, the future climate predictions (e.g., whether precipitation will increase or decrease), and species response to the change in climate, which taken together may result in poor model predictions of reserves and linkages that wildlife can use in the future (Beier and Brost 2010). Land facets are subject to less uncertainty by incorporating fewer variables with uncertainty.

The steps we implemented to design land facet corridors are described below. Unless otherwise stated, most of the tools we used in this analysis came from the ArcGIS toolbox and R package called 'Land Facet Corridor Designer' written by Jeff Jenness, Brian Brost, and Paul Beier (www.corridordesign.org) implemented in ArcGIS 10 (ESRI 2012) and R statistical software (R-project 2013).

3.11.1 Topographic Position Raster

The first step in land facet corridor analysis was to classify the study area into topographic classes, which were later further divided into land facets. We used the Topographic Position Index (TPI) tool to create a 3-class topographic position categorical raster that broadly classifies the landscape into canyons, ridges, and slopes. The slopes class included all the pixels that were not classified as either canyon or ridge, including flat areas. TPI was calculated as the difference between a cell's elevation value and the mean elevation of the neighborhood around the cell, with positive values indicating the cell was higher than the mean of its surrounding cells while negative values indicated the cell was lower than the mean of its surrounding cells. If the difference between a cell's elevation and the mean elevation of the neighborhood was greater than a user-defined elevation threshold, then the cell was classified as a ridge (if the cell was higher than the neighborhood) or a canyon (if the cell was lower than the neighborhood). All other cells were classified as slopes. TPI was highly influenced by the choice of the neighborhood size (i.e., the number of pixels surrounding the cell used in the neighborhood mean calculation) and the threshold elevation value selected to classify the landscape into the respective topographic classes. We tested several neighborhood sizes and threshold values, and based on visual inspection of TPI classes overlaid on aerial imagery in areas where we were familiar with the topography, we determined that a neighborhood size of 7 (210 meter radius) and threshold elevation value of 8 meters best represented the topography in the northern Sierra Nevada foothills.

3.11.2 Define and Map Land Facets

Each topographic class was then further classified into land facets. Land facets in canyon and ridge classes were defined based on elevation and slope (steepness as a continuous variable) whereas land facets in slopes class were defined using annual solar insolation in addition to slope and elevation. We used the 30 m resolution National Elevation Dataset (NED) digital elevation model as a source for the elevation data. We extracted slope angle in degrees from the 30 m resolution NED digital elevation model to characterize the steepness of the study area. We generated the insolation layer from the 30 m elevation data using the 'Area Solar Radiation' tool in ArcGIS 10. Annual solar insolation is defined as a measure of solar radiation energy received on a given surface area recorded during a given time. Units are in watt-hours per square meter (Wh/m^2). The tool calculated the sum of instantaneous radiation at half-hour intervals for one day per month over a calendar year as a function of latitude, aspect, slope and topographic shading.

3.11.3 Develop land facet corridors

We generated least-cost corridors for each land facet and each pair of landscape blocks. Just as core habitat patches within landscape blocks were connected for the wildlife species corridors, "termini", or clusters of land facet raster cells, were connected between landscape blocks for land facets. The cumulative cost raster for each land facet and each pair of landscape blocks was used as the resistance surface to generate the least-cost corridors. To evaluate the land facet corridors, we calculated percent land facet density in each land facet corridor.

We used a similar rule set to the focal species corridors to select the final land facet corridors, using the following questions:

1. Is the corridor continuous after urban mask is applied?
2. Does corridor provide sufficient land facet pixels? Are the "pixel patches" within a 250 m dispersal distance?

3.12 Comparison of corridor types

We compared all three corridor types (focal species, riparian and land facet) with the predicted habitat of the nine passage species to see how well each corridor type captured wildlife habitat needs. We classified the nine passage species habitat into four categories: habitat values of zero, values from 1-50 were classed as low, 51-75 as medium and 76-100 as high. We then determined how much low, medium, and high suitability habitat was present in each corridor. We calculated what percentage of corridor represented habitat area, as well as how the total habitat area in each corridor compared to total habitat available.

We also compared the landscape blocks, linkages, riparian corridors and land facet corridors to other conservation project data to compare how well the fine-scale connectivity areas captured conservation priorities in the study area. We calculated area of each polygon in the comparison data, calculated areas of overlap with the landscape blocks and linkages, and derived statistics within GIS. We compared our data with CDFW Habitat Conservation and Natural Community Conservation Plans and USFWS designated Critical Habitat.

3.13 Attributes of landscape blocks, least-cost corridors and linkages

Each landscape block, least-cost corridor and linkage is represented as a polygon shapefile, which is a two-dimensional area in map space. Each shapefile has a list of attributes providing detailed information about the biological and physical traits of each polygon. Table 6 describes the attributes, statistics, characteristics and data sources used for calculation. We used ArcMap 10.1 (ESRI 2012) Zonal Statistics to generate summary statistics (min, mean, max); Calculate Geometry to calculate area and length; and Corridor Designer Evaluation Tools to calculate percent width. Table 7 provides a full list of attributes calculated for each corridor.

Table 2. Statistics used to describe landscape block, least-cost corridors and linkage polygons.

Statistic	Characteristics for which this statistic was used
Sum	Area of polygon
Proportion (%) of area in the polygon belonging to a certain classification (pixel)	Landcover classes (vege15) Land protection classes (GAP Status 1-4) Rarity-weighed richness hotspots Vernal pool Critical habitat BLM Area of Critical Environmental Concern Habitat patch Habitat suitability
Mean, range and standard deviation across all pixels for polygon	Elevation
Length	Length of least-cost path within corridor/linkage
Count and List	Ecoregions Ecoregions Subsections Counties Watersheds Major road crossings Critical habitat species CNDDB plant and animal
Density (km per km^2)	Major roads

Table 7. Attribute table fields for corridor GIS shapefiles.

	Descriptor	Data Source	Limitations	Acronym
Identifier	Unique number for LB, LCC or Linkage			Block_ID CorridorID LinkageID
	Name of landscape block (LB)			Block_Name
Landform	Mean, Min, Max and Standard Deviation of Elevation	Digital Elevation Model (270 m)		Elev_mean Elev_min Elev_max Elev_std
	Elevation range: difference between minimum and maximum elevation	Digital Elevation Model (270 m)		Elev_range
Polygon Area	Area of polygon in ac	Calculated in GIS		Area_ac
	Area of polygon in hectares	Calculated in GIS		Area_ha
Co rri do	Identifying numbers of LB			Block_A Block_B

	Descriptor	Data Source	Limitations	Acronym
	connected by the corridor or linkage			
	Length of corridor or linkage (m)	Measured in GIS, based on least-cost model		Length_m
Protections Status	Percent protected as GAP 1, 2, 3 or conservation easements	California Protected Areas Database (CPAD - www.calands.org), National Conservation Easement Database (NCED - http://www.conservationeasement.us/)		Pc_protect
	Percent protected as GAP 1, 2 or conservation easements			Pc_gap12e
	Percent protected as GAP 3			Pc_gap3
	Percent protected as GAP 4			Pc_gap4
	Percent private, unprotected status			Pc_priv
ACEC	Percent in BLM Areas of Critical Environmental Concern based on biological values	http://www.geocommunicator.gov/ ARCGIS/REST/services/ACEC/MapServer		
Habitat for listed species	Percent in USFWS designated Critical Habitat for federally listed species	GIS data provided by USFWS		Pc_crithab
	Number of species with Critical Habitat in the polygon			N_crithab
Species Diversity	Number of special status plant taxa occurring in polygon according to CNDDB and other CDFW datasets	http://www.dfg.ca.gov/ biogeodata/		N_CNDDB_p
	Number of special status animal taxa occurring in polygon according to CNDDB and other CDFW	http://www.dfg.ca.gov/ biogeodata/		N_CNDDB_a

	Descriptor	Data Source	Limitations	Acronym
	datasets			
	Percent in amphibian, reptile, mammal or plant rarity hotspot	http://www.dfg.ca.gov/ biogeodata/ace/		Pc_hotspot
Wetland	Percent in wetland or vernal pool	Carol W. Witham, Robert F. Holland and John Vollmar. 2013. 2005 Great Valley Vernal Pool Map, Plus Merced, Placer and Sacramento County Losses 2005-2010. Sacramento, CA. Report prepared for the U.S. Fish and Wildlife Service's and Bureau of Reclamation's CVPIA Habitat Restoration Program under Grant Agreement No. 80270-A-G509 with the USFWS.		Pc_wtvp
Roads	Number of times the polygon is intersected by major roads	ESRI Major Roads		Mjrd_cross
	Density of major roads (km/km^2)	ESRI Major Roads, Total length divided by polygon area		Mjrd_dens
Ecoregions	Number of USDA ecoregions that intersect the polygon	USDA Ecoregions California07_3		N_ecoreg
	List of ecoregions that intersect the polygon			ecoregs
	Number of USDA subsections that intersect the polygon			N_sebsect
	List of USDA subsections that intersect the polygon			subsect
Watersheds	Number of watersheds that intersect the polygon	HUName Calw221		N_HU
	List of watersheds that intersect the polygon			HU_name
Counties	Number of counties that intersect the polygon			N_counties

	Descriptor	Data Source	Limitations	Acronym
	List of counties that intersect the polygon			counties
Landcover	Percent classed as urban	vege_15 vegetation raster		Pc_urban
	Percent classed as chaparral			Pc_chprl
	Percent classed as conifer			Pc_cnfr
	Percent classed as coastal conifer			Pc_cconfr
	Percent classed as grassland			Pc_grslnd
	Percent classed as hardwood			Pc_hrdwd
	Percent classed as juniper			Pc_juniper
	Percent classed as mixed conifer			Pc_mx_confr
	Percent classed as oak woodland			Pc_oak
	Percent classed as orchard			Pc_orchard
	Percent classed as cropland			Pc_crop
	Percent classed as shrub			Pc_shrub
	Percent classed as water or wetland			Pc_wet

4 Results

4.1 Landscape Blocks

We identified 238 blocks of land to connect (Figure 2). The landscape blocks represent National Park Service, National Forest Service, Bureau of Land Management, Department of Defense, state, county and city lands and private lands under conservation easement. The landscape blocks represent 1,317,384.6 ha of land. Of which, 58% are protected lands with GAP 1, 2, 3 or conservation easement status. The landscape blocks cover a diverse group of vegetation and habitat with 22.5% in mixed conifer, 17.5% in grassland, 13.8% in oak woodland and 12.1% hardwood.

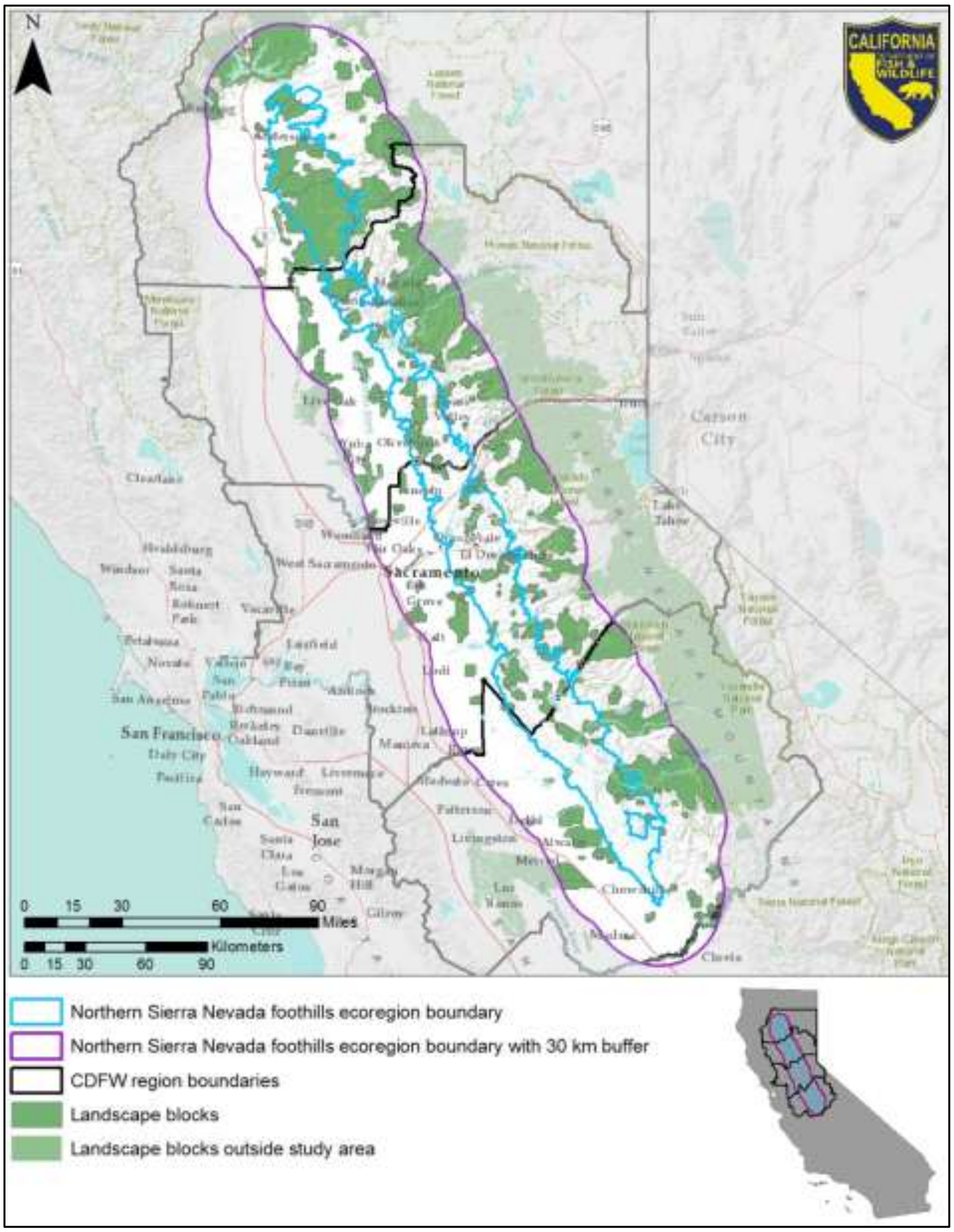

Figure 2. Map of landscape blocks, protected lands to connect with least-cost corridor analysis.

4.2 Habitat Suitability

Maxent models were chosen for 23 of the focal species, CWHR BioView for seven species. The Maxent models generally showed accuracy within the range of well-performing models (AUC > 0.75; Swets, 1988). AUC values for the BioView models are lower than the Maxent models because the BioView models are not based on species location data.

Predicted habitat varied across the study area according to each species life history and ecological needs. We predicted the smallest area of habitat for limestone salamander (41,079.2 ha), a highly specialized species known to occur in only one county in California. The largest area of habitat predicted was for California ground squirrel (4,352,334.1 ha), a wide-ranging, burrowing generalist. Detailed information for each focal species is located in the species account section of this report.

Table 8. Habitat model scenario selection, model performance measured by AUC, threshold value, and total predicted habitat area in hectares for focal species selected for connectivity analysis.

Common Name Scientific Name	Selected habitat model	AUC	Threshold	Predicted habitat (ha)
Acorn Woodpecker *Melanerpes formicivorus*	S7	0.75	0.29	3,359,596.5
Arboreal Salamander *Aneides lugubris*	S9	0.96	0.10	820,066.7
Black Bear *Ursus americanus*	S9	0.94	0.12	2,214,680.1
Black-tailed Jackrabbit *Lepus californicus*	S9	0.80	0.31	1,848,875.2
Bobcat *Lynx rufus*	Expert Opinion	0.56	-	4,235,118.2
California Ground Squirrel *Spermophilus beecheyi*	Expert Opinion	0.57	-	4,352,334.1
California Kangaroo Rat *Dipodomys californicus*	S5	0.96	0.10	896,035.8
California Quail *Callipepla californica*	S5	0.75	0.29	4,015,346.6
California Thrasher *Toxostoma redivivum*	S6	0.79	0.29	2,979,167.9
Coast Horned Lizard *Phrynosoma coronatum*	S6	0.81	0.28	1,464,320.4
Cooper's Hawk *Accipiter cooperii*	S6	0.73	0.34	3,325,902.1
Dusky-footed Woodrat *Neotoma fuscipes*	S9	0.88	0.21	4,032,886.3
Foothill Yellow-legged Frog *Rana boylii*	S7	0.95	0.16	2,084,386.0
Gopher Snake *Pituophis catenifer*	Expert Opinion	0.61	-	4,122,407.5

Common Name Scientific Name	Selected habitat model	AUC	Threshold	Predicted habitat (ha)
Gray Fox *Urocyon cinereoargenteus*	Expert Opinion	0.50	-	4,345,219.1
Heermann's Kangaroo Rat *Dipodomys heermanni*	S5	0.95	0.10	1,033,284.6
Lark Sparrow *Chondestes grammacus*	S7	0.81	0.32	2,899,211.1
Limestone Salamander *Hydromantes brunus*	S9_GEO	0.99	0.10	41,079.2
Mountain Lion *Puma concolor*	S5	0.91	0.16	2,864,773.2
Mountain Quail *Oreotyx pictus*	S7	0.78	0.23	1,616,980.3
Mule Deer *Odocoileus hemionus*	S6	0.75	0.34	3,529,387.9
Northern Pygmy Owl *Glaucidium gnoma*	S7	0.88	0.21	2,821,711.1
Pallid Bat *Antrozous pallidus*	Expert Opinion	0.56	-	4,348,900.5
Racer *Coluber constrictor*	Expert Opinion	0.60	-	3,716,274.3
Southern Alligator Lizard *Elgaria multicarinata*	S6	0.85	0.27	2,946,800.3
Spotted Towhee *Pipilo maculatus*	Expert Opinion	0.59	-	3,185,649.8
Western Gray Squirrel *Sciurus griseus*	S9	0.9	0.18	2,586,871.1
Western Pond Turtle *Actinemys marmorata*	S7	0.94	0.14	2,468,627.3
Wood Duck *Aix sponsa*	S6	0.95	0.17	1,054,068.4
Yellow-billed Magpie *Pica nuttalli*	S9	0.89	0.14	3,750,355.1

4.3 Corridor and Patch Analysis

We conducted least-cost corridor analysis for nine focal species (black bear, black-tailed jackrabbit, bobcat, dusky-footed woodrat, gray fox, mountain lion, mule deer, Western gray squirrel and Western pond turtle). The least-cost corridors were based on species specific habitat models and consisted of 47 black bear corridors, 105 black-tailed jackrabbit corridors, 81 bobcat corridors, 98 dusky-footed woodrat corridors, 85 gray fox corridors, 66 mountain lion corridors, 134 mule deer corridors, 99 Western gray squirrel corridors and 84 Western pond turtle corridors, with many species corridors overlapping. For many connections there was overlap in the corridors of at least two species despite diverse needs and the use of species specific data to build the habitat suitability models. The corridors capture each species habitat well, with the majority of corridors capturing at least 75% of the species habitat.

We conducted the patch analysis for all focal species. Limestone salamander was predicted to have the fewest habitat patches (5) across the study area. While black-tailed jackrabbit had the largest number of habitat patches, with 2,571. Sixty-nine percent of the total habitat area met the size requirements to be classified as habitat patches. Detailed information for each focal species is located in the species account section of this report.

4.4 Focal Species Accounts

The following pages provide detailed information about each focal species including life history information, model results, and final maps of habitat suitability models, patch analysis, and least cost corridors.

Life history information was taken from Department species accounts (Zeiner et al. 1990, CWHR 2008), and a literature search was conducted for each species. A list of focal species references is provided at the end of this section.

We split the study area into four sections for easier representation on the maps. The study area was split into four sections from north to south based on California Department Fish and Wildlife region boundaries (Regions 1, 2 and 4). Region 2 was further split into a northern and southern section by county boundary. A map of the final habitat suitability model used in the analysis is included for each focal species. For passage species, maps of the final least cost corridors for the species are included; for corridor dwellers, maps of the patch analysis showing population and breeding patches are included.