APPENDIX C. DETAILED METHODS AND RESULTS FOR MODELING SPECIES-SPECIFIC CONNECTIVITY, MULTI-SPECIES CONNECTIVITY, AND ROAD CROSSING LOCATIONS

METHODS

Overview

To identify road crossings and assess landscape-level corridors across the study area, we (1) identified focal species and available data for those species, (2) ran spatially-explicit models to estimate habitat use and resistance to movement across the study area for each species, (3) modeled connectivity and road crossing locations for each species, and (4) combined results across species. We used two different study area extents in the modeling for this project. The first was all of San Diego County. This extent was used in developing the Species Distribution Models (SDMs), the point and path selection functions, and the landscape genetics models. The second study area was focused on the SR-67 area and was used for all connectivity and road crossing analyses. We first identified the SR-67 region of interest and then buffered this area by five kilometers to account for possible edge effects in the connectivity models. A detailed description of the SR-67 study area is provided in the main report.

Focal species selection and data sources are also described in detail the main report. The gold standard for modeling species-specific connectivity is to use movement data from GPS telemetry collars or genetic data, or a combination of these two data types. Therefore, we used these data for the species for which it was available. However, the collection of these data types is often costly and time consuming and it was only available for a few of our focal species. For the remaining species, we used available detection data compiled from a range of sources. Different analytical techniques are required to analyze these different data types. For detection data, we used ensemble species distribution models, for GPS telemetry data we used point and path selection functions, and for the genetic data we used a landscape genetics modeling approach that we then combined with our other analytical products.

After initial modeling, we transformed the resultant surfaces from each SDM or movement model into resistance and modeled connectivity across the resistance surfaces using resistant kernel (Compton *et al.* 2007) and OmniScape models (McRae *et al.* 2016). We combined the connectivity surfaces across all our focal species to derive a multi-species connectivity surface from which corridors were delineated. We also modeled land facet corridors and added corridors in areas that were not well represented by the multi-species corridor (Appendix E). To identify road crossing locations, we used the species-specific resistance surfaces to run Factorial Least Cost Paths (Cushman *et al.* 2014). We identified road crossing locations at the intersection of the species-specific least cost paths and the roads of interest in the study area.

In the following sections, we provide detailed methods on (1) ensemble species distribution modeling (SDM) for California mouse, mule deer, big-eared woodrat, and wrentit; (2) point and path selection function models for bobcat and puma; (3) landscape genetics analyses for bobcat, mule deer and puma; (4) resistance surface development for

each species; (5) connectivity modeling for each species and development of a multi-species connectivity surface and corridor; and (6) modeling road crossing locations.

Environmental Variables

We used the same environmental variables across all species and for all models with the exception of the puma models. The puma models were mostly derived from a previous modeling exercise (Zeller *et al.* 2017b) conducted in collaboration with Drs. Winston Vickers and Walter Boyce at the University of California – Davis, Karen C. Drayer Wildlife Health Center Southern California Mountain Lion Project, and Dr. Holly Ernest at the University of Wyoming.

We identified environmental variables that might affect habitat use and movement for all focal species (Table C1). Because the thematic resolution of environmental variables has been shown to affect model performance and prediction ability, we represented some variables with multiple thematic resolutions (*e.g.*, all roads vs. primary roads) to determine the optimal representation of each variable (Zeller *et al.* 2017a).

Species respond to environmental variables at different spatial scales and recently, multi-scale models have been shown to outperform single scale models for species-habitat relationships (Johnson *et al.* 2004, Wheatley and Johnson 2009, McGarigal *et al.* 2016). Therefore, we assessed environmental variables across a range of scales for each species by applying a Gaussian smooth to each surface using the *smoothie* package (v 1.0-1, Gilleland 2013) in the R software environment (R Core Team 2013). The largest scale was based on previous knowledge of the species habitat use or estimated dispersal distances. We used scales ranging from 30 m to 180 m for California mouse, woodrat, and wrentit, scales ranging from 30 m to 2,160 m for mule deer, scales ranging from 30 m to 2,000 m for bobcat, and scales ranging from 30 m to 10,000 m for puma.

Ensemble Species Distribution Modeling

Presence points

Presence points for mule deer, woodrat, California mouse and wrentit were collected from a variety of sources to obtain adequate sample sizes and geographic coverage across San Diego County (Table C2). All points were filtered by date and spatial accuracy so that only points observed after 1990 with an accuracy of 500 m were retained. We observed a general lack of presence points in the desert-dominated eastern part of the county. Therefore, we masked that area of the county from the analysis for all species.

In contrast to data collected as part of a thoughtful and thorough sampling regime, opportunistic data is subject to sampling bias. This sampling bias often results in inadequate representation of the environmental space, which leads to environmental bias in SDM model results and inaccurate model predictions (Phillips *et al.* 2009). We took two approaches to address sampling bias, (1) we spatially filtered out points that were close together based on nearest neighbor distances (Fourcade *et al.* 2014), and (2) we spatially restricted the sampling of background points (described in *'Background points'* section below). For mule deer, we filtered out all points within 1 km of each other. For California mouse, woodrat, and wrentit, we filtered out all points within 500 m of each other.

Table C1. Environmental variables used in developing all the species-specific models, with the exception of puma, whose point and path selection functions and landscape genetic analyses were conducted as part of a prior study with the University of California, Davis.

	Variable	Source/Derivation	Year	Citation
Roads and Development	All Roads	Open Street Map	2014	Open Street Map 2014
	Primary roads	Open Street Map; Motorways	2014	
	Secondary roads	Open Street Map; primary road, secondary road, and trunk road	2014	
	Tertiary roads	Open Street Map; living street, residential, rest area, road, service, tertiary, and unclassified	2014	
	Unpaved roads/trails	Open Street Map; bridleway, cycleway, footway, path, and track,	2014	
	Percent Imperviousness	Derived from a hybrid of the National Land Cover Database percent impervious surface and updated data from the San Diego Association of Governments land use surface	2011/ 2012	NLCD 2011 (Jin *et al.* 2013), SANDAG 2012
Topography	Elevation	National Elevation Dataset	2009	USGS 2009
	Percent Slope	Derived from National Elevation Dataset	-	-
	Terrain Ruggedness	Total curvature derived from National Elevation Dataset with DEM Surface Tools (Jenness 2013)	-	-
	Topographic Position Index	Derived from National Elevation Dataset	-	-
	Ridges	Derived from Topographic Position Index values >= 8		
	Canyons	Derived from Topographic Position Index values <=- 8		
	Steep Slope	Derived from Topographic Position Index values -8 – 8, slope >=6°		
	Gentle Slope	Derived from Topographic Position Index values -8 – 8, slope <=6°		
Water	Streams	National Hydrography Dataset streams layer	2011	USGS 2011
	Distance to Water	Derived from National Hydrography Dataset calculated as Euclidean distance to blue line streams		
Vegetation Type	Agriculture	Vegetation Data of San Diego County	2014	SANDAG 2014
	Chaparral	Vegetation Data of San Diego County	2014	SANDAG 2014
	Coastal Scrub	Vegetation Data of San Diego County	2014	SANDAG 2014
	Coniferous Forest	Vegetation Data of San Diego County	2014	SANDAG 2014
	Desert Scrub	Vegetation Data of San Diego County	2014	SANDAG 2014
	Hardwood Forest	Vegetation Data of San Diego County	2014	SANDAG 2014
	Herbaceous Grassland	Vegetation Data of San Diego County	2014	SANDAG 2014
	Riparian	Vegetation Data of San Diego County	2014	SANDAG 2014
	Sparse/Disturbed	Vegetation Data of San Diego County	2014	SANDAG 2014
	Water and Wetlands	Vegetation Data of San Diego County	2014	SANDAG 2014

The resulting points for each species were examined for potential landscape change due to human development by overlaying the points with urban and roads data. We removed all points where landscape change was suspected to have occurred after the observation.

These data cleaning steps resulted in retaining 722 presence points for mule deer, 202 points for woodrat, 216 points for California mouse, and 1,481 points for wrentit. Presence points were sampled on each of the scaled environmental variable surfaces. Presence points are displayed for each species in Appendix D.

Table C2. Data Sources for presence-only and presence-absence locations. Citations are as follows: 1) San Diego Natural History Museum, *In Prep*; 2) County of San Diego 2016; 3) eBird 2016; 4) Jennings and Lewison 2013; 5) Marine Corps Base Camp Pendleton, *Unpublished Data*; 6) Center for Natural Lands Management, *Unpublished Data*; 7) San Diego Management and Monitoring Program 2016

Species ***(scientific name)***	**Data type(s)**	**Data source(s)**
California mouse *(Peromyscus californicus)*	Presence points	SDNHM Mammal Atlas[1], SanBIOS[2]
Big-eared woodrat *(Neotoma macrotis)*	Presence points	SDNHM Mammal Atlas[1], SanBIOS[2]
Wrentit *(Chamaea fasciata)*	Presence & absence points	eBIRD[3]
Mule deer *(Odocoileus hemionus californicus*)	Presence points	SDNHM Mammal Atlas[1], SanBIOS[2], SDSU[4], MCB Camp Pendleton[5], CNLM[6], SDMMP MOM[7]

Background points

The data for mule deer, California mouse, and woodrat required the selection of pseudo-absence or background points. From a visual inspection of the presence points for these species, it appeared they were heavily biased toward primary and secondary roads in the study area. We confirmed this bias by sampling the presence points on a distance from roads surface (*e.g.* Figure C1). We counted the number of presence points within each 500 m distance from roads bin and randomly sampled the same number of background points in each distance from roads bin, generating a 1:1 ratio with the presence points for each species (Barbet-Massin *et al.* 2012).

We took a different approach for wrentit since the eBIRD database contained actual absence points in the form of observation locations where wrentit were not seen. We randomly selected the same number of background points as presence points from the eBIRD data for wrentit. We assumed background locations to have the same sampling bias as presence locations and therefore did not spatially restrict the wrentit background points like we did for the other species. Background points for each species were sampled on each of the scaled environmental variable surfaces. Background points are displayed for each species in Appendix D.

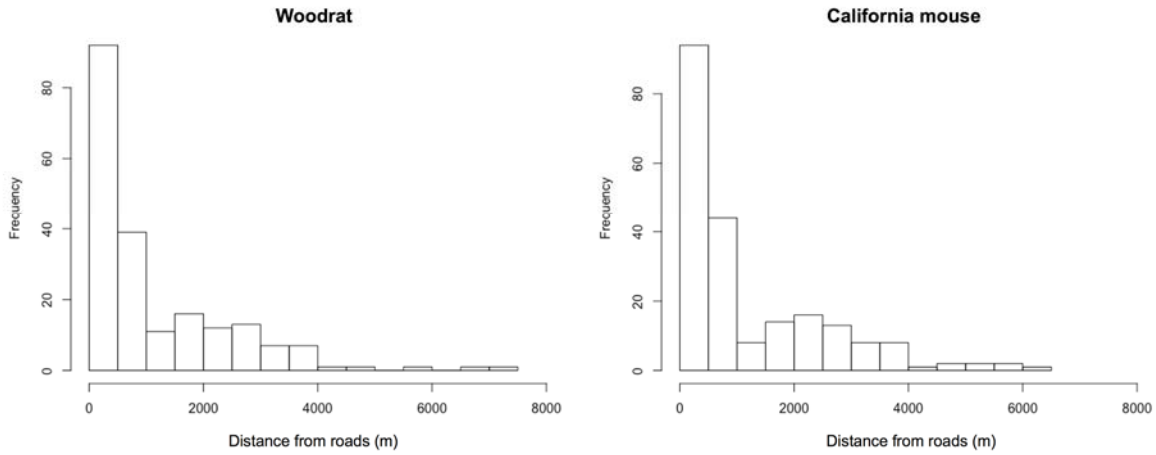

Figure C1. Example of spatial sampling biases in presence-only data. Histograms show distance from primary and secondary roads for California mouse and big-eared woodrat presence points.

Species Distribution Models

There are many models considered appropriate for analyzing presence-background data – all with various advantages and disadvantages (Franklin 2009). In the absence of having one single model that outperforms all others, using multiple models to produce a final 'ensemble' model has been proposed as the optimal way to estimate presence-background models (Araujo and New 2007). Ensemble models have been shown to produce more robust predictions and to perform better than single presence-background models (Araujo and New 2007, Grenouillet *et al.* 2011).

We selected three regression methods (Generalized Linear Models (GLMs); Generalized Additive Models (GAMs); Multivariate adaptive regression splines (MARs)) and three machine-learning methods (Random Forests (RF); Boosted Regression Trees (BRT); MAXENT) for our suite of SDM models. We did not select any classification models such as Classification Tree Analysis because we desired a continuous output for our predictive surfaces.

We used the *BIOMOD2* package in R to run all SDMs and generate our final ensemble model for each species (Thuiller *et al.* 2016). We performed a 10-fold cross validation procedure for all models to assess model predictive ability. Across the 10 folds, we calculated the area under the receiver operating characteristic curve (AUC), and used this as our model performance metric.

We used a two-step pseudo-optimized approach to create our multi-scale SDMs (McGarigal *et al.* 2016). First we ran univariate models for each environmental variable at each scale. We selected the scale that had the largest AUC value across the majority of models for inclusion in the multivariate models. Though some methods we used did not require independence among predictor variables for the multivariate models, others did. Therefore, we assessed the correlation between the predictor variables at their best scales

and omitted the variable with the lowest AUC among pairs of variables with a correlation coefficient, $|r_s| > 0.6$.

Multivariate models with an AUC > 0.75 were retained and used to generate an ensemble model. We used the *BIOMOD2* package and the final ensemble model for each species to predict habitat suitability across San Diego County.

Point and Path Selection Functions

For bobcat and puma we used GPS telemetry data collected from previous studies to run the point and path selection functions (Jennings and Lewison 2013, Zeller *et al.* 2017b). The puma analyses were carried out over a study area extent reaching from approximately Interstate 8 in the south to the city of Santa Ana in Orange County to the north. For bobcat, we used the same study areas described above.

For bobcat, trapping and collaring were conducted by San Diego State University project staff between 2009 and 2012 in accordance with the California Fish and Game Scientific collecting Permit #SCP-009632 and SDSU Animal Protocol #10-09-027L). Bobcats were fit with a TCG181, TCG271, or Quantum 4000 GPS collar (Sirtrack Ltd., Havelock North, New Zealand; Telemetry Solutions, Concord, California, USA). Collars were programmed to collect a GPS location every three hours for five days out of every week and every hour for two days out of every week. Due to collar failure and animals that were unable to be relocated after a period of time, data were retrieved from eight of the collared cats (7 male and 1 female). GPS data were cleaned to remove points with large spatial error or locations after the collar drop-off mechanism was activated.

For the point selection function, we subset the bobcat data to every three hours so that the data were consistent, and to reduce any autocorrelation that may have been present with the hour-long fixes. This resulted in 3,895 of points for the point selection function analysis. For the path selection function, we used only the GPS collar data that were collected hourly for each day the collar was on that schedule. We then connected each consecutive point with a straight line, which resulted in 86 daily paths for use in the analysis (mean for each individual = 12 days, range = 3 - 44).

For puma, trapping and collaring were conducted by University of California, Davis, Karen C. Drayer Wildlife Health Center Southern California Mountain Lion Project between 2005 and 2016 under California Fish and Wildlife Scientific Collecting Permit number 9875 and University of California Davis Institutional Care Use Committee authorization number 17233. Capture details and protocols are detailed in Vickers *et al.* (2015). GPS acquisition interval varied from 5-minutes to 6-hours. We removed two-dimensional fixes with a Position Dilution of Precision > 5 to avoid the use of data with potentially large spatial errors (Lewis *et al.* 2007).

For the point selection function, we used data from 31 pumas that had at least 5 months of data. Similar to bobcat, we subset the puma data to every 6 hours to reduce any autocorrelation in the data and so that the data were consistent across individuals. This resulted in 24,911 locations with a per-individual mean of 811 points (range = 284 – 1,535). For the path selection function, we used only GPS locations that were collected at a 5 or 15-minute interval. We created paths for each individual by connecting consecutive

points over each 24-hour time period. This resulted in a total of 39 pumas and 1,076 daily paths for the path selection function (mean per individual = 30 days, range = 14–106).

Point selection functions

The point selection functions were used to estimate the relative probability of habitat use and to identify resource use patches. These resource use patches were also used in the connectivity models for placing source points – locations where movement originated for the connectivity models for these two species.

We then estimated the used data as the proportion (for categorical data) or mean (for continuous data) of each predictor variable within a 30 m uniform buffer around each GPS location. We estimated the available data within a larger ecological neighborhood around each used point represented with a Gaussian kernel (Addicott *et al.* 1987). Therefore, each used point is paired with an ecologically relevant available area. Conceptually, this point selection function design is akin to comparing where an individual was located (used point) with where it could have been located within a biologically relevant movement area (available neighborhood). This approach, also referred to as a context-dependent point selection function, allows for habitat selection to be estimated at each location across the study area based on its location and surrounding environment (Zeller *et al.* 2014).

We developed our multi-scale models using a two-stage, pseudo-optimized approach (McGarigal *et al.* 2016). In the *coxme* package (Therneau 2015a), we ran univariate models for each predictor variable at each scale in a paired (a.k.a. conditional) logistic regression model with a random effect for individual (Compton *et al.* 2002). The scale with the lowest corrected Akaike's Information Criteria (AICc) value for each variable was identified as the characteristic scale of selection and was a candidate for incorporation into the multiple regression models.

We tested for collinearity among our predictor variables at their characteristic scales using Spearman's rank correlations. If two variables had $|r_s| > 0.60$ we retained the variable with the highest AIC model weight. The multiple regression models did not converge in the mixed-effects framework; therefore, we ran the multiple regression models without mixed-effects using the coxph function of the *Survival* package (Therneau 2015b). To compensate for the lack of an individual level mixed-effect, we used robust standard errors, which are calculated by combining data into clusters such that the clusters are not autocorrelated (Nielson *et al.* 2002, Hardin and Hilbe 2003, Fortin *et al.* 2005). Robust errors are often used to control for the individual-level effects in paired regression models (Fortin *et al.* 2005, Forester *et al.* 2009). We then fit all possible subsets of our predictor variables with the dredge function in the *MuMIn* package (Bartoń 2016). We used this approach because we had no *a priori* hypotheses to consider any specific combinations of variables and we thought all variables would be influential for bobcat habitat use. We ranked the models using AICc and arrived at our final model by averaging any models within 2 AICc units of the best model. We used the robust standard errors when calculating confidence intervals for the model-averaged coefficients.

We used the final point selection function model to predict the relative probability of habitat use across the study area by first calculating the proportion or mean of each predictor variable within a 30 m buffer around each cell within the study area. We then calculated the proportion or mean of each predictor variable around each cell in the study area weighed by the Gaussian kernel for that predictor variable at its characteristic scale. This is akin to the used and available from the logistic regression models. We then differenced the available from the used for each cell within the study area and applied our model-averaged coefficients to create each predictive surface.

Path Selection Functions

We performed Path Selection Functions to estimate the relative probability of movement for bobcats and pumas across the study area (Cushman *et al.* 2010, Zeller *et al.* 2016). We took much the same approach as for the point selection functions above, but our units of inference were the daily paths used by the individual cats. We estimated the used data as the proportion (for categorical data) or mean (for continuous data) of each predictor variable within a 30 m uniform buffer around each daily path. The available data were the proportion or mean of the predictor variables around each path weighted by the scaled environmental variables described above.

We ran paired logistic regression models and used a two-stage, pseudo-optimized approach for the multi-scale path selection function models via the same process described for the point selection function analysis above.

We used the final path selection function model to predict the relative probability of movement across the study area.

Landscape Genetic Analysis

The bobcat genetic data were collected and genotyped by San Diego State University. Between 2006 and 2012, 61 individual bobcats were sampled and nuclear DNA was extracted and characterized at 22 microsatellite loci.

The mule deer genetic data were collected and genotyped by USGS and San Diego State University (Mitelberg and Vandergast 2016, Bohonak and Mitelberg 2014). Between 2005 and 2015, 223 individual deer were sampled throughout the study area. Nuclear DNA was extracted and characterized at 15 microsatellite loci.

The puma genetic data were collected and genotyped by the University of California, Davis, Karen C. Drayer Wildlife Health Center Southern California Mountain Lion Project and the University of Wyoming (Ernest *et al.* 2014, Gustafson *et al.* 2017). Between 2001 and 2016, blood or tissue samples were collected from 139 captured or deceased pumas across the greater study area. Nuclear DNA was extracted and characterized at 44 microsatellite loci.

Landscape genetic approaches correlate observed genetic distances among individuals with resistance distances. These resistance distances are often calculated as the least-cost distance among individuals across resistance surfaces defined *a priori*. We explored a number of different resistance hypotheses for each of our environmental variables. We represented each variable using the same scales described above for each species. We

then applied seven functions to transform each scaled variable into a resistance value of 1–100 (Figure C2). Positive or negative transformation functions were used to represent increasing or decreasing resistance with increasing values of that variable, respectively. We also used the inverse Ricker transformation to account for variables that might have a low resistance at moderate values.

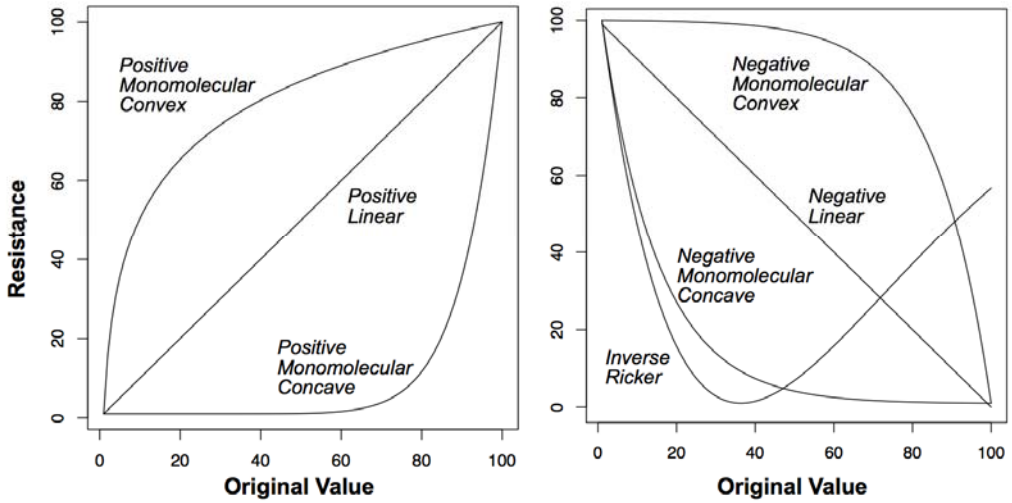

Figure C2. Functions used to transform the environmental variables to resistance, with a range of 1-00, for use in the landscape genetic analysis. Figure adapted from Zeller *et al.* 2017b.

With the *adegenet* package (Jombart 2008), we calculated pairwise genetic distances among all individuals for each species. We calculated pairwise geographic distance by calculating the least cost path distance between all sample locations across each *a priori* resistance surface with the *gdistance* package (van Etten 2015). We then compared all the *a priori* resistance surfaces for a variable by running univariate linear mixed effects models that accounted for the pairwise structure of the distance matrices following the maximum likelihood population-effects (MLPE) method (Clarke *et al.* 2002, van Strien *et al.* 2012).

We used AICc to identify the most appropriate resistance surface for each variable. We assessed correlations among variables and removed variables from correlated pairs with higher AICc values. We then ran multiple regression models with all uncorrelated variables and fit all possible subsets of the variables. We ranked the multiple regression models using AICc and identified our final top model for each species.

Resistance surfaces

All resistance surface and connectivity modeling was focused on the SR-67 study area.

For species with SDM models, we rescaled the habitat suitability surfaces generated from *BIOMOD2* from 0-1,000 to 0-100. Recent studies on large mammals and birds have found habitat use was not linearly related to resistance and that individuals are more

tolerant of sub-par environmental features when dispersing than when occupying territories or home ranges (*e.g.*, Keeley *et al.* 2016, Trainor *et al.* 2013, Mateo-Sánchez *et al.* 2015). To account for this possibility we used a non-linear transformation to transform the habitat suitability values to resistance (Figure C3, Keeley *et al.* 2016).

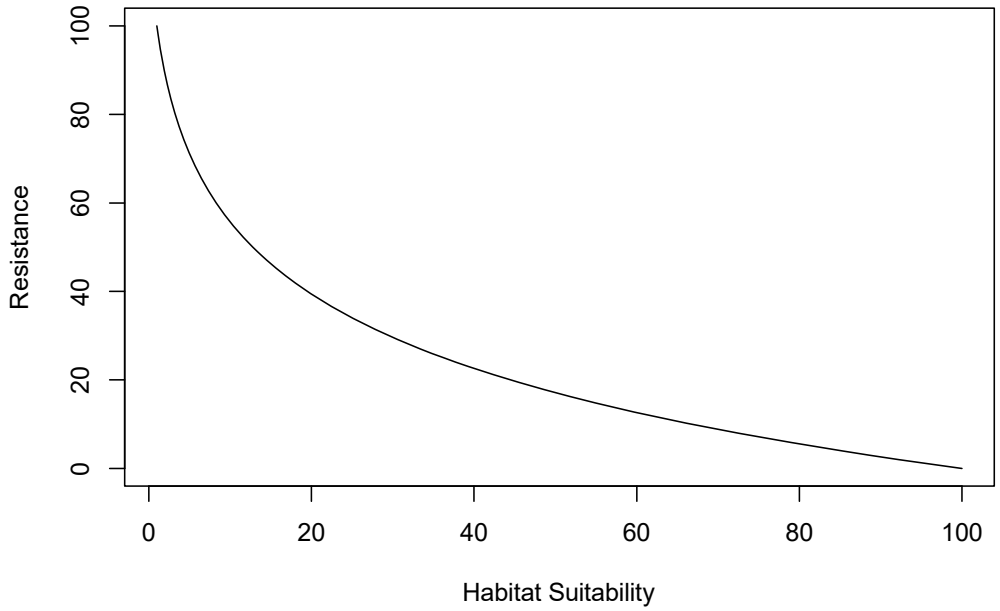

Figure C3. Transformation used to estimate resistance from habitat suitability. Resistance was calculated from the following formula: 100-99*((1-exp(-4 * habitat suitability))/(1-exp(-4))). Figure and formula adapted from Keeley *et al.* (2016).

For species with path selection functions, we linearly rescaled the predicted probability of movement surfaces to resistance. We used a linear rescale because the predicted surfaces estimate movement directly so no assumptions need to be made in translating this surface to resistance.

For species with landscape genetic models, we summed the resistance surfaces for the variables in the final model and rescaled this final surface to have a range of 1–100.

For bobcat and puma, we combined the resistance surfaces derived from the genetic analysis with the resistance surfaces derived from the path selection functions. For mule deer, we combined the resistance surface derived from the genetic analysis with the resistance surface derived from the SDM. The combination of resistance surfaces resulted in a multi-level resistance surface for each species that accounts for both movement across the landscape and successful breeding over generations (Zeller *et al.* 2017b). Resistance surfaces were combined by multiplying the two resistance surfaces together and rescaling the final values from 1-100.

Connectivity modeling and development of multi-species connectivity surface and corridor

We employed two different connectivity models for all our focal species; resistant kernels (Compton *et al.* 2007) and OmniScape (McRae *et al.* 2016). Unlike least-cost path type connectivity models, resistant kernels and OmniScape provide a continuous connectivity surface and allow for the incorporation of biologically relevant dispersal distances. Continuous connectivity surfaces provide a value for every pixel on the landscape regardless of protected area or jurisdictional boundaries. Across the resistance surface for each species we ran resistant kernel models with UNICOR software (Landguth *et al.* 2012) and OmniScape with Python software provided by B. McRae (personal communication). Dispersal distances for bobcat, California mouse, mule deer, puma, woodrat, and wrentit were 18,000 m, 800 m, 8,000 m, 24,00 m, 1,600 m, and 1,000 m, respectively.

Resistant kernels require the identification of source points, from which flow is modeled. For species with SDMs, we identified source points across the study area by probabilistically sampling 1,000 points on the habitat suitability surface for each species. This sampling results in more points being placed in areas with higher habitat suitability than lower suitability. For species with point selection function models, we first identified habitat patches across the study area by identifying areas that had at least a relative probability of use of 60%. We then probabilistically sampled 1,000 source points on the probability of use surface within the habitat patches. For the OmniScape models, we identified sources as any pixel in the resistance surface for each species that had a value less than 20.

To create a connectivity surface that reflected the needs of multiple species, we averaged the resistant kernel connectivity surfaces across the six focal species. We then quantile rescaled this surface so it ranged from 0-100. We identified a multi-species corridor by taking the top 30% of this surface (connectivity values of 70-100%). This cut-off was the minimum value that provided both east-west and north-south connectivity among preserved lands within our study area. We performed the same procedure with the OmniScape connectivity surfaces. There were many similarities between the resistant kernel result and the OmniScape results, therefore we retained the corridor boundaries from the resistant kernels and supplemented them with areas from the OmiScape surface that helped enforce east-west and north-south connectivity across the study area.

Road Crossing Locations

As recommended by Cushman *et al.* (2014), we identified road crossing locations by modeling Factorial Least Cost Paths (FLCPs) across the study area for each species and identifying points where the FLCPs crossed a road of interest.

To make this analysis computationally feasible, we used 300 of the 1,000 source points described above. We then used UNICOR software (Landguth *et al.* 2012) to model FLCPs between all pairs of source points across the resistance surface for each species.

The FLCP results provide the number of least cost paths that cross each pixel in the study area. We retained any pixel with a value of 250 paths or more. We then identified where these pixels crossed SR-67 and other roads of interest in the study area. To pinpoint road crossing hotspots, we located areas where multiple crossing locations were with 300 m of one another. These road crossing zones were the basis for the infrastructure plan.

RESULTS

Ensemble Species Distribution Modeling

Based on the results of our univariate models, California mouse selected for environmental variables at either the 90 m or 180 m scale, and only distance from water was better represented at a smaller scale (60 m). After accounting for correlations among variables, the final variable set for the California mouse SDM models included agriculture, canyons, chaparral, coastal scrub, elevation, hardwood forest, herbaceous grassland, primary and secondary roads, riparian areas, percent slope, sparsely vegetated areas, steep slopes, streams, TPI, and water/wetlands (Table C3).

Mule deer selected for environmental variables at a wide range of scales, from 90 m to 2,160 m. After accounting for correlations among variables, the final variable set for the mule deer SDM models included agriculture, chaparral, coastal scrub, coniferous forest, desert scrub, elevation, hardwood forest, herbaceous grassland, riparian, water and wetlands, primary roads, elevation, topographic position index, steep slopes, and distance to water (Table C3).

Big-eared woodrat also selected for variables at a wide range of scales, selecting for TPI, elevation, and canyons at a 30 m scale, chaparral, hardwood forest, and riparian areas at a 60 m scale and the remaining variables at the 90 m or 180 m scales. After accounting for correlations among variables, the final variable set for the woodrat SDM models included agriculture, canyons, chaparral, coastal scrub, elevation, hardwood forest, herbaceous grassland, primary and secondary roads, riparian areas, percent slope, sparsely vegetated areas, steep slopes, streams, TPI, and water/wetlands (Table C3).

Wrentit selected for most environmental variables at the 360 m scale. After accounting for correlations among variables, the final variable set for the wrentit SDM models included agriculture, canyons, chaparral, coastal scrub, elevation, hardwood forest, herbaceous grassland, primary and secondary roads, riparian areas, impervious surfaces, steep slopes, distance to water, topographic position index, and water/wetlands (Table C3).

After developing the models for each species and projecting the SDMs across San Diego County, we asked local species experts to examine the outputs. Species experts for all but mule deer deemed the SDM models to be appropriate. For mule deer, the model tended to under-predict habitat suitability. Given that no additional presence data were available for deer to use for model improvement, we looked to other data sources and ran an additional analysis for deer with genetic data (described in methods and in landscape genetics results below).

AUC model performance values for each individual SDM model and the final ensemble models are provided in Table C4. Predicted habitat suitability surfaces for each species are provided in Appendix D.

Table C3. Variables and scales included in the final SDM models for California mouse, mule deer, woodrat, and wrentit. Variables without scales indicate it was not included in the final model for that species.

	Variable	Scale included in final SDM model			
		California mouse	***Mule deer***	***Woodrat***	***Wrentit***
Roads and Development	All Roads				
	Primary roads	180 m	1,440 m	90 m	360 m
	Secondary roads	180 m		180 m	180 m
	Tertiary roads				
	Unpaved roads/trails				
	Percent Imperviousness		90 m		60 m
Topography	Elevation	90 m	2,160 m	30 m	360 m
	Percent Slope	90 m		180 m	
	Terrain Ruggedness Index				
	Topographic Position	180 m	90 m	30 m	90 m
	Ridges				
	Canyons	180 m			360 m
	Steep Slope	90 m	360 m	180 m	360 m
	Gentle Slope				
Water	Streams	180 m		90 m	
	Distance to Water		90 m		360 m
Vegetation Type	Agriculture	90 m	1,440 m	180 m	360 m
	Chaparral	180 m	360 m	60 m	360 m
	Coastal Scrub	180 m	720 m	180 m	360 m
	Coniferous Forest		2,160 m		
	Desert Scrub		2,160 m		
	Hardwood Forest	180 m	2,160 m	60 m	360 m
	Herbaceous Grassland	180 m	720 m	60 m	360 m
	Riparian	90 m	720 m	60 m	360 m
	Sparse/Disturbed	180 m		180 m	
	Water and Wetlands	180 m	2,160 m	180 m	360 m

Table C4. SDM model performance for California mouse, mule deer, woodrat, and wrentit. All models with an AUC > 0.75 were included in the final ensemble model. GLM = Generalized Linear Model, GAM= Generalized Additive Model, MARS= Multivariate adaptive regression splines, RF=Random forests, BRT=Boosted regression trees.

	AUC			
Model	**California mouse**	**Mule deer**	**Woodrat**	**Wrentit**
GLM	0.83	0.78	0.80	0.79
GAM	0.80	0.78	0.79	0.80
MARS	0.83	0.78	0.79	0.80
RF	0.88	0.78	0,82	0.82
MAXENT	0.78	0.72	0.72	0.80
BRT	0.87	0.79	0.82	0.82
Ensemble	0.87	0.80	0.82	0.82

Point and Path Selection Functions

Point Selection Functions

For bobcat, the univariate results indicated selection for resources almost exclusively at coarser scales (with the exception of Herbaceous Grassland and Water/Wetland). We were unable to fit models with Coniferous Forest or Desert Scrub, due to the scarcity of these habitat types in the study area where the bobcats were collared. We were also unable to fit models with Agriculture due to complete separation errors.

Bobcats consistently responded negatively to human influences (roads and development), and positively to canyons, water and riparian areas. Bobcats avoided ridges, steep slopes and higher elevations, but preferred higher amounts of topographic roughness (curvature).

After accounting for collinearity among predictor variables we attempted to run a global model with the following variables: All Roads, Canyons, Chaparral, Coastal Scrub, Hardwood Forest, Herbaceous Grassland, Riparian, Sparse Distributed, Elevation, Percent Slope, Steep Slopes, Distance to Water, Streams, and Water/Wetland. However, the Canyons variable was causing a Type S error in the beta coefficient (Gelman and Tuerlinckx 2000), therefore, we removed Canyons, and re-ran the global model. Performing dredge on the global model revealed four top models. Model-averaged standardized beta coefficients, robust standard errors, and 95% confidence intervals, are provided in Table C5.

For puma, the univariate model results indicated a mostly bi-modal response to landscape features. Pumas responded to elevation, percent slope, chaparral, and coastal scrub at fine scales and responded to the other variables at coarse scales. Due to convergence errors, we were unable to fit the models for desert and primary roads.

Table C5. Variable scales, standardized beta estimates, robust standard errors, and 95% robust confidence intervals for the bobcat point selection function model-averaged variables.

	Scale	Beta estimate	Standard Error	95% Confidence Interval
All Roads	1,000 m	-0.287	0.037	-0.309 – -0.265
Chaparral	1,000 m	1.236	0.114	1.167 – 1.305
Coastal Scrub	1,000 m	0.349	0.061	0.312 – 0.386
Distance to Water	1,000 m	-0.257	0.061	-0.294 – -0.220
Elevation	1,000 m	-7.190	0.354	-7.404 – -6.976
Hardwood Forest	1,000 m	0.301	0.051	0.270 – 0.332
Steep Slopes	1,000 m	-0.142	0.048	-0.113 – -0.171
Percent Slope	1,000 m	1.115	0.110	1.049 – 1.181
Sparse Distributed	1,000 m	-0.176	0.044	-0.203 – -0.149
Streams	519 m	0.138	0.036	-0.160 – -0.116
Riparian	1,000 m	0.006	0.018	-0.005 – 0.017
Water/Wetland	170 m	0.007	0.016	-0.002 – -0.017
Herbaceous Grassland	275 m	-0.007	0.024	-0.022 – -0.008

After removing correlated variables, the global model was identified as the top model. Pumas preferred slightly more rugged terrain, riparian areas and woodland while avoiding high elevation, high slopes, agriculture, barren, chaparral, coastal scrub, grassland, urban, and primary, secondary, and tertiary roads (Table C6).

Table C6. Variable scales, standardized beta estimates, robust standard errors, and 95% robust confidence intervals for the puma point selection function variables.

	Scale	Beta estimate	Standard Error	95% Confidence Interval
Elevation	241 m	-21.61	0.60	-21.99 – -21.23
Percent Slope	24 1m	-1.1	0.03	-1.12 – -1.08
Terrain Ruggedness	4,461 m	0.09	0.01	0.08 – 0.09
Agriculture	4,461 m	-0.25	0.02	-0.23 – -0.26
Barren	3,994 m	-0.06	0.02	-0.05 – -0.07
Chaparral	241 m	-0.17	0.06	-0.21 – -0.13
Coastal Scrub	681 m	-0.29	0.03	-0.03 – -0.27
Grassland	4,461 m	-0.38	0.02	-0.40 – -0.37
Riparian	3,497 m	0.38	0.04	0.35 – 0.40
Woodland	4,461 m	0.23	0.02	0.22 – 0.24
Urban	4,461 m	-2.18	0.16	-2.28 – -2.08
All roads	4,461 m	-0.06	0.02	-0.07 – -0.05

The predicted relative probability of use surfaces for bobcat and puma across San Diego County are provided in Appendix D.

Path Selection Functions

For bobcats, we were unable to fit the path selection function models with Coniferous Forest or Desert Scrub vegetation variables due to the lack of representation described above. Bobcats selected more landscape variables at finer scales during movement than during resource use (Table C7). After accounting for collinearity among predictor variables, we attempted to run a global model with the following variables: Agriculture, All Roads, Chaparral, Coastal Scrub, Herbaceous Grassland, Riparian, Sparse Distributed, Elevation, Steep Slopes, Distance to Water, and Water/Wetland. However, as in the point selection function models, Agriculture was causing the models to fail due to complete separation errors. Therefore, we removed Agriculture, and re-ran the global model. Eighteen top models within 2 AICc units of the top model were identified. Model-averaged standardized beta coefficients, standard errors, and confidence intervals are provided in Table C7.

Table C7. Scales, standardized beta estimates, robust standard errors, and 95% robust confidence intervals for the bobcat path selection function model-averaged variables.

	Scale	Beta estimate	Standard Error	95% Confidence Interval
Elevation	519 m	-12.562	3.370	-15.152 – -9.972
All roads	465 m	-2.07	0.712	-2.617 – -1.523
Sparse Distributed	519 m	-0.693	0.821	-1.324 – -0.062
Distance to Water	1,000 m	-0.349	0.534	-0.759 – 0.061
Herbaceous Grassland	170 m	-0.392	0.661	-0.900 – 0.116
Steep Slopes	519 m	-0.241	0.449	-0.586 – 0.104
Riparian	275 m	0.059	0.196	-0.092 – 0.210
Chaparral	519 m	0.010	0.130	-0.090 – 0.110

Pumas also selected landscape variables at finer scales more often during movement than during resource selection (Table C8). After removing correlated variables, four top models were identified and beta coefficients were averaged. Pumas also showed more tolerance for a wider range of landscape variables during movement than during resource-use events. Pumas avoided steep slopes, agricultural areas, urban areas, and roads during movement, but showed a preference for all other landscape variables in the final model, especially riparian and woodland areas (Table C8).

Table C8. Scales, standardized beta estimates, robust standard errors, and 95% robust confidence intervals for the puma path selection function model-averaged variables.

	Scales	Beta estimate	Standard Error	95% Confidence Interval
Elevation	241 m	9.22	1.00	8.51 – 9.94
Percent Slope	2,797 m	-1.35	0.21	-1.50– -1.20
Agriculture	3,819 m	-0.02	0.09	-0.08 – 0.05
Chaparral	3,104 m	1.44	0.30	1.37 – 1.51
Grassland	2,797 m	-0.02	0.28	-0.22 – 0.18
Barren/Open Water	3,104 m	-0.02	0.07	-0.07 – 0.04
Riparian	1,317 m	5.92	1.90	4.56 – 7.27
Woodland	241 m	2.87	0.36	2.61 – 3.13
Urban	241 m	-7.53	2.03	-8.98 – -6.08
All roads	3,819 m	-0.78	0.24	-0.95 – -0.62

Landscape Genetics Analysis

For all species, the linear mixed effect models resulted in identifying a single scale and transformation to resistance for each variable out of the suite of *a priori* resistance surfaces tested. After accounting for correlations, the following variables were included

in the multiple regression model for bobcat: agriculture, all roads, chaparral, coastal scrub, hardwood forest, herbaceous grassland, riparian, steep slopes, streams, terrain ruggedness, topographic position index and water and wetland (Table C9). Most of the transformations selected for bobcat indicate the lowest resistance values are at moderate values of that variable. However, resistance for bobcats steadily increased with the amount of roads and water and wetlands on the landscape and decreased with the amount of chaparral and coastal scrub.

For mule deer, the following variables were included in the final model: agriculture, chaparral, coastal scrub, distance to water, elevation, gentle slope, hardwood forest, herbaceous grassland, primary and secondary roads, riparian, sparsely vegetated/urban, steep slopes, streams, topographic position index, and water and wetland (Table C9). Resistance for mule deer increased with increasing values of roads, slope, urban, and coniferous forest. Resistance for mule deer decreased with elevation, topographic position index, distance to water, riparian, agriculture and chaparral. Resistance was lowest at moderate values of hardwood forest and streams.

For puma, after accounting for correlations, the following variables were included in the multiple regression model: elevation, percent slope, agriculture, chaparral, coastal scrub, coastal oak woodland, grassland, riparian, urban, and primary roads (Table C9). Variables whose resistance decreased with increasing values were chaparral, percent slope, riparian, coastal scrub, and coastal oak woodland. Resistance for elevation and ruggedness were represented by an Inverse Ricker transformation, which decreases until middle values are reached, and then increases for the remaining values, indicating dispersal is facilitated at mid-elevation and mid-ruggedness values.

Resistance surfaces

Resistance surfaces for each species are provided in Appendix D.

Connectivity modeling and development of multi-species connectivity surface and corridor

Species-specific connectivity model results for resistant kernel and OmniScape approaches are provided in Appendix D. The multi-species connectivity surface and resultant corridors are provided in the main report as well as attributes for the final multi-species corridor. The final corridor was divided into sub-corridors based upon protected lands and other important landscape features. A detailed description of each sub-corridor is provided in Appendix A.

Road Crossing Locations

Species-specific FLCP maps are provided in Appendix D. All road crossing points and multi-species road crossing zones are presented and described in the main report and Appendix B.

Table C9. Final model variables, scales and transformations to resistance for bobcat, mule deer, and puma. Variables without scales or transformations indicate it was not included in the final model for that species. Plus or minus indicates preference or avoidance of that variable for or movement. A forward slash refers to the inverse Ricker transformation, which indicates the lowest resistance values correspond with values in the middle of the range of values for that variable. The selected resistance transformation for the landscape genetic analysis are indicated by IR = inverse Ricker, NL = negative linear, NMCc = negative monomolecular concave, NMCv = negative monomolecular convex, PL = positive linear, PMCc = positive monomolecular concave, PMCv = positive monomolecular convex.

		Bobcat		Mule deer		Puma	
	Variable	***Scale***	***Trans-formation/ Sign***	***Scale***	***Trans-formation/ Sign***	***Scale***	***Trans-formation/ Sign***
Roads and Development	All Roads	2,000 m	PL -				
	Primary roads			2,160 m	PMCc -	500 m	PMCv -
	Secondary roads			1,440 m	PMCc -		
	Tertiary roads						
	Unpaved roads/trails						
	Percent Imperviousness						
Topography	Elevation			720 m	NMCc +	6,000 m	IR /
	Percent Slope					8,000 m	NMCc +
	Terrain Ruggedness	465 m	IR /				
	Topographic Position Index	2,000 m	IR /	1,440 m	NMCc +		
	Ridges						
	Canyons						
	Steep Slope	170 m	IR /	720 m	PMCv -		
	Gentle Slope			90 m	PL -		
Water	Streams	465 m	IR /	1,440 m	IR /		
	Distance to Water			720 m	NMCc +		
Vegetation Type	Agriculture	465 m	IR /	720 m	NMCc +	6,000 m	PL -
	Chaparral	1,000 m	NL +	180 m	NMCv +	6,000 m	NMCc +
	Coastal Scrub	2,000 m	NMCv +	1,440 m	PMCv -	500 m	NMCv +
	Coniferous Forest						
	Desert Scrub						
	Hardwood Forest	170 m	IR /	90 m	IR /	2,000 m	NMCv +
	Herbaceous Grassland	2,000 m	IR /	90 m	PL -	500 m	PMCv -
	Riparian	170 m	IR /	2,160 m	NMCc +	500 m	NMCv +
	Sparse/Disturbed			2,160 m	PMCv -	500 m	PMCv -
	Water and Wetlands	2,000 m	PL -	720 m	PL -		

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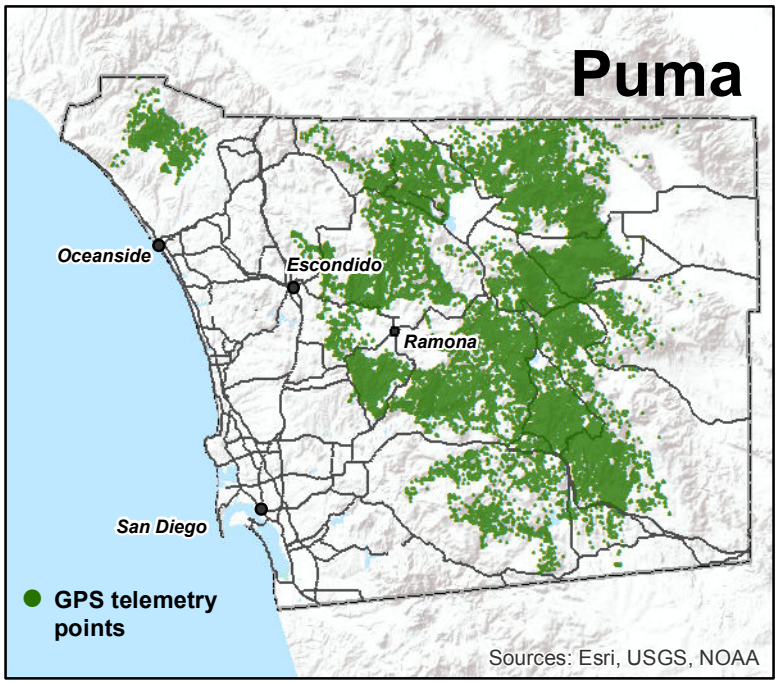
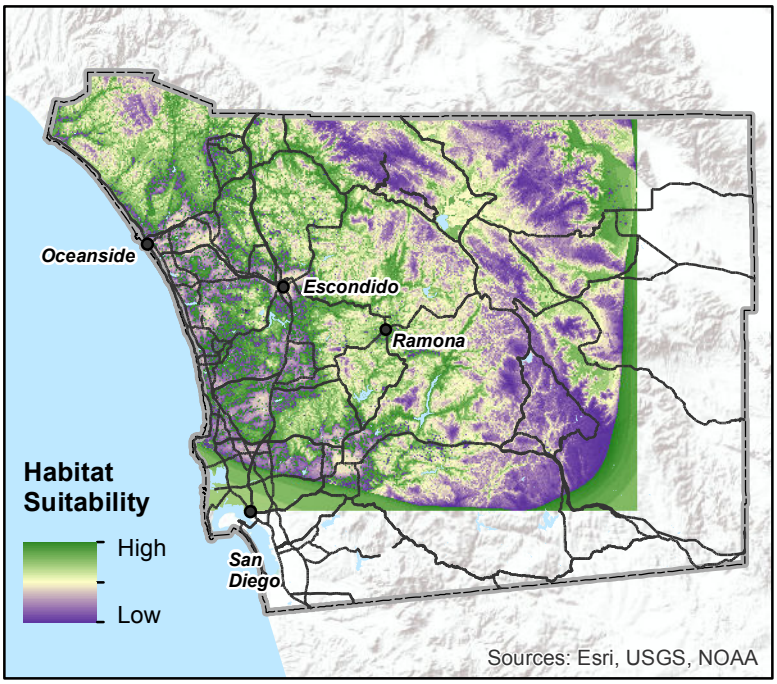
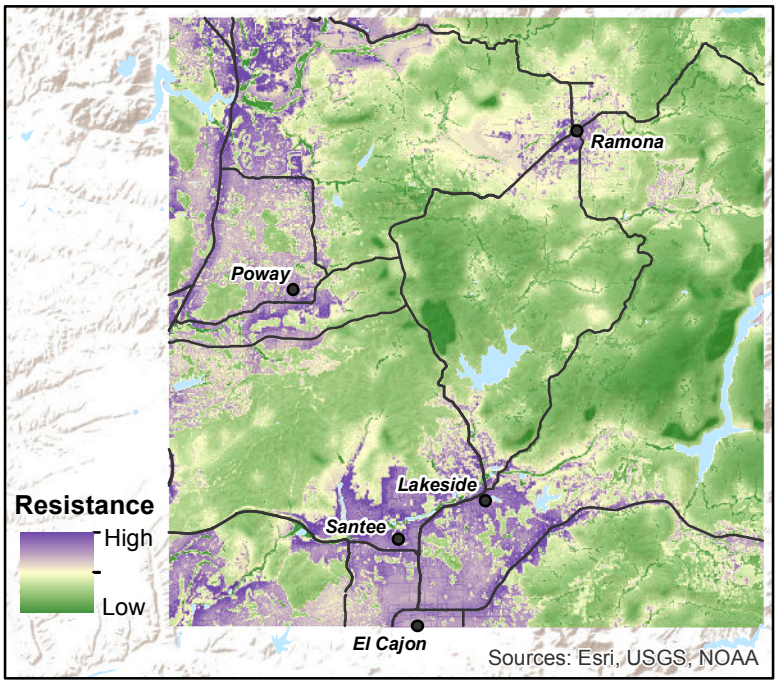
APPENDIX D: SPECIES-SPECIFIC MODELING INPUTS AND RESULTS

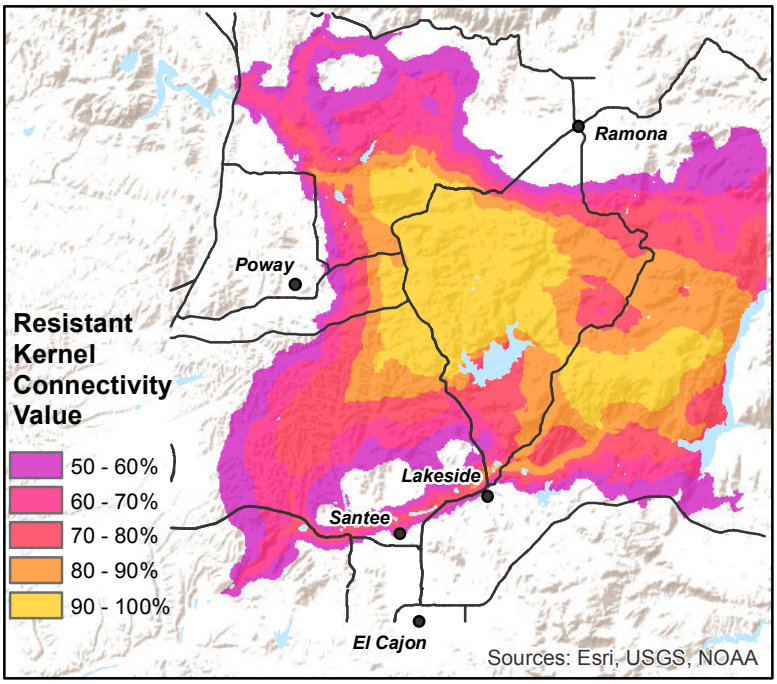
The following are panels of maps for the six focal species modeled in the following order: 1) Puma, 2) Bobcat, 3) Mule deer, 4) Big-eared woodrat, 5) California mouse, and 6) Wrentit. Each page consists of the following map panels:

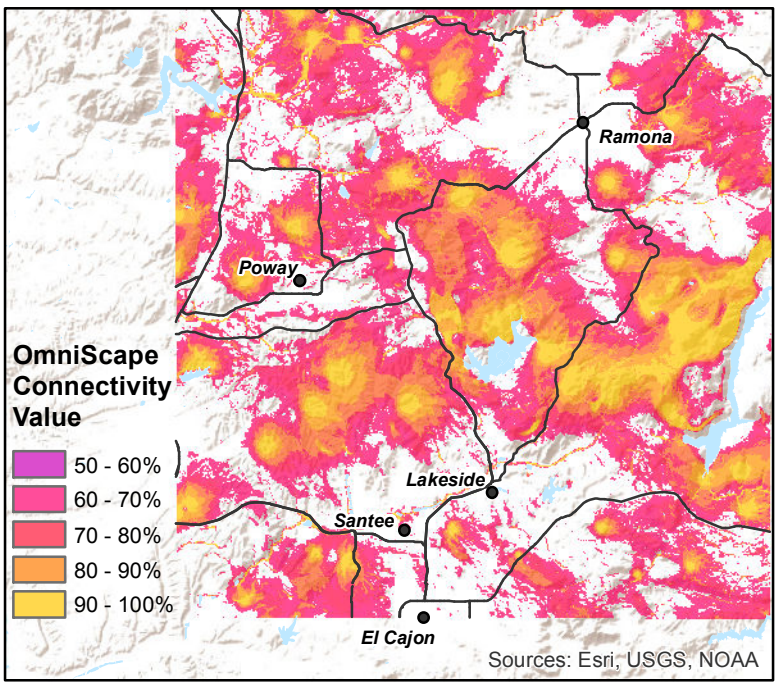
- Upper left – Telemetry points; Presence and background points; or Presence and absence points for each species
- Upper right – Habitat suitability surface
- Center left – Landscape resistance surface
- Center right – Resistant kernel connectivity value
- Bottom left – Omniscape connectivity value
- Bottom right – Factorial least cost paths and road crossing locations

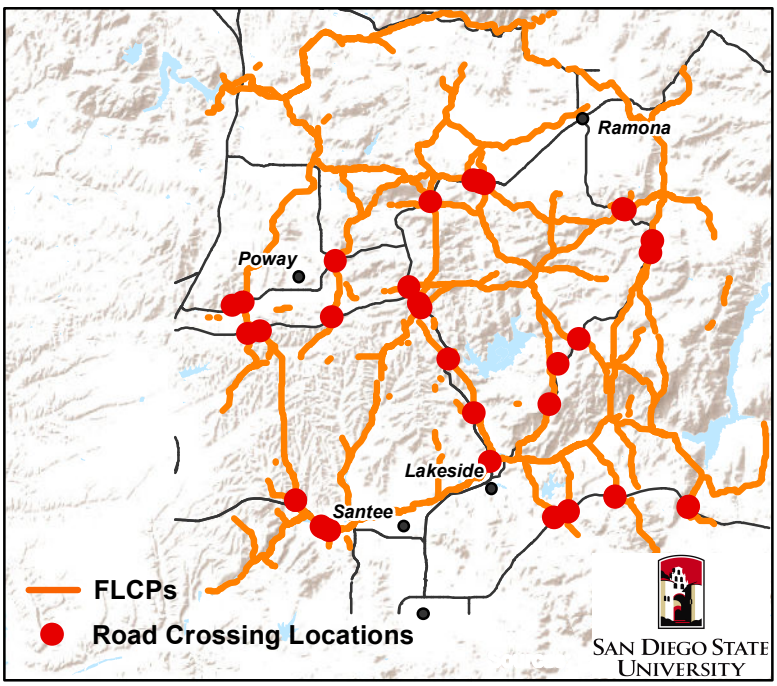

Puma
Oceanside
Escondido
Ramona
San Diego
GPS telemetry points
Sources: Esri, USGS, NOAA


Oceanside
Escondido
Ramona
San Diego
Habitat Suitability
High
Low
Sources: Esri, USGS, NOAA


Ramona
Poway
Lakeside
Santee
El Cajon
Resistance
High
Low
Sources: Esri, USGS, NOAA


Ramona
Poway
Lakeside
Santee
El Cajon
Resistant Kernel Connectivity Value
50 - 60%
60 - 70%
70 - 80%
80 - 90%
90 - 100%
Sources: Esri, USGS, NOAA


Ramona
Poway
Lakeside
Santee
El Cajon
OmniScape Connectivity Value
50 - 60%
60 - 70%
70 - 80%
80 - 90%
90 - 100%
Sources: Esri, USGS, NOAA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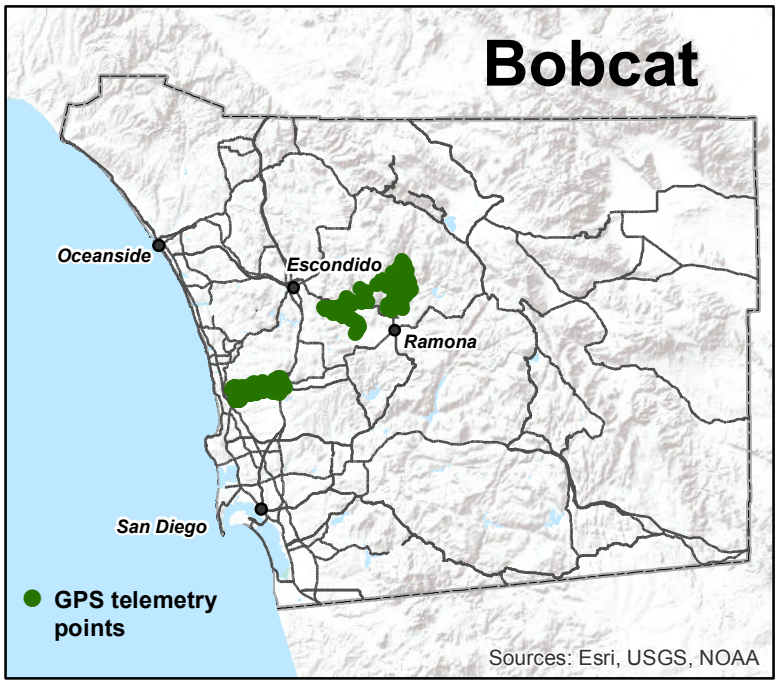
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San Diego
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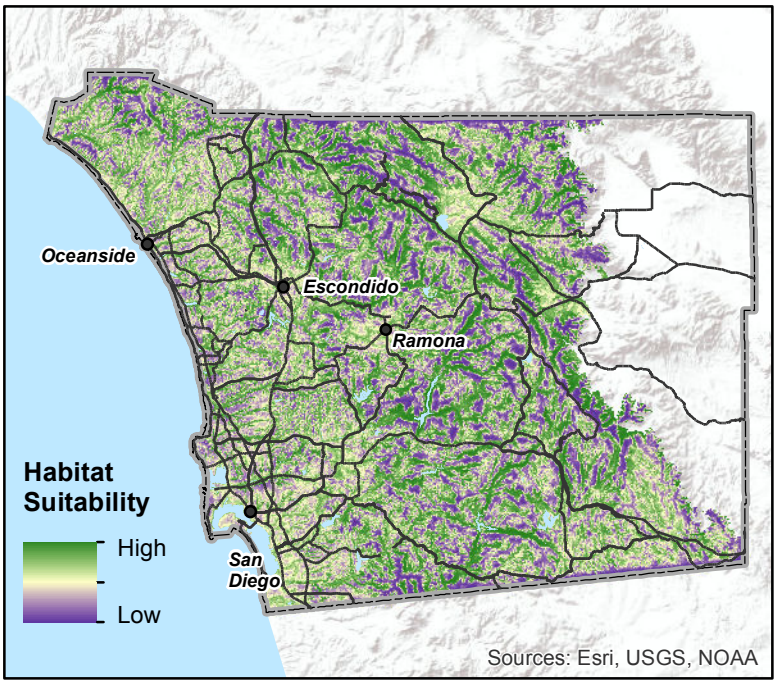
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Ramona
San Diego
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Low
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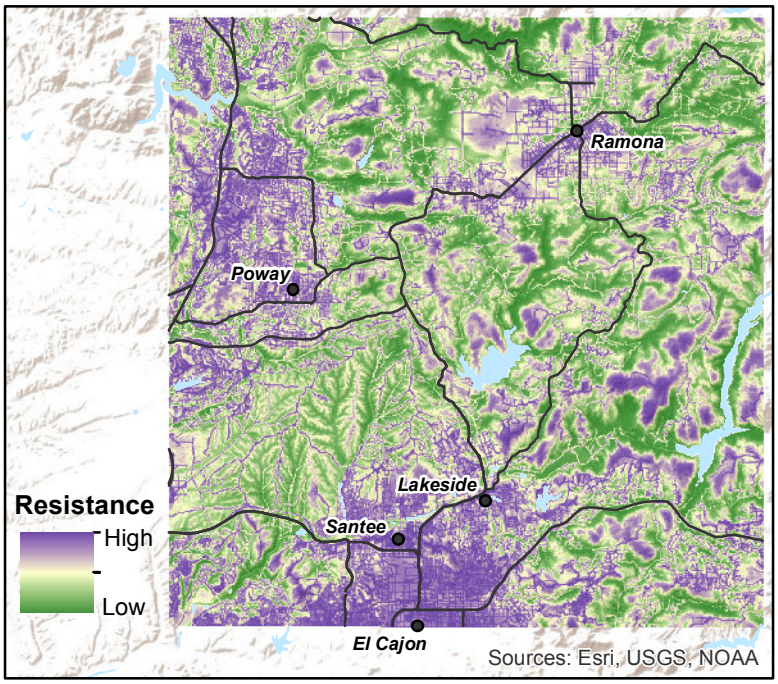
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Lakeside
Santee
El Cajon
Resistance
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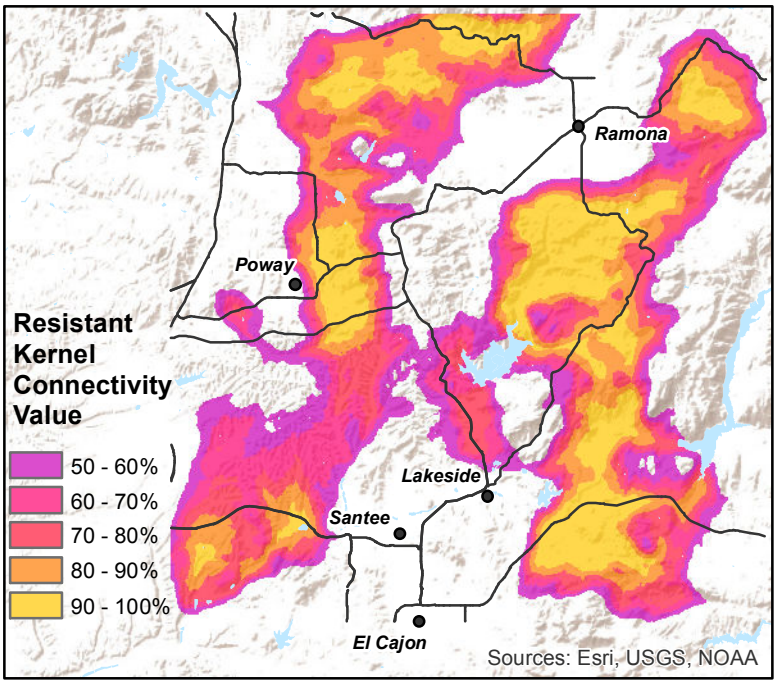
Low
Sources: Esri, USGS, NOAA


Ramona
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Lakeside
Santee
El Cajon
Resistant Kernel Connectivity Value
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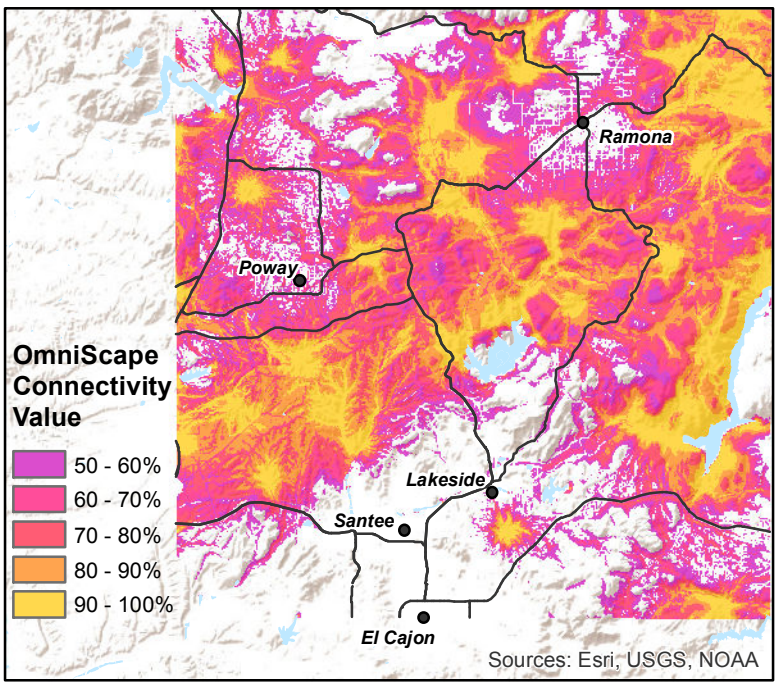
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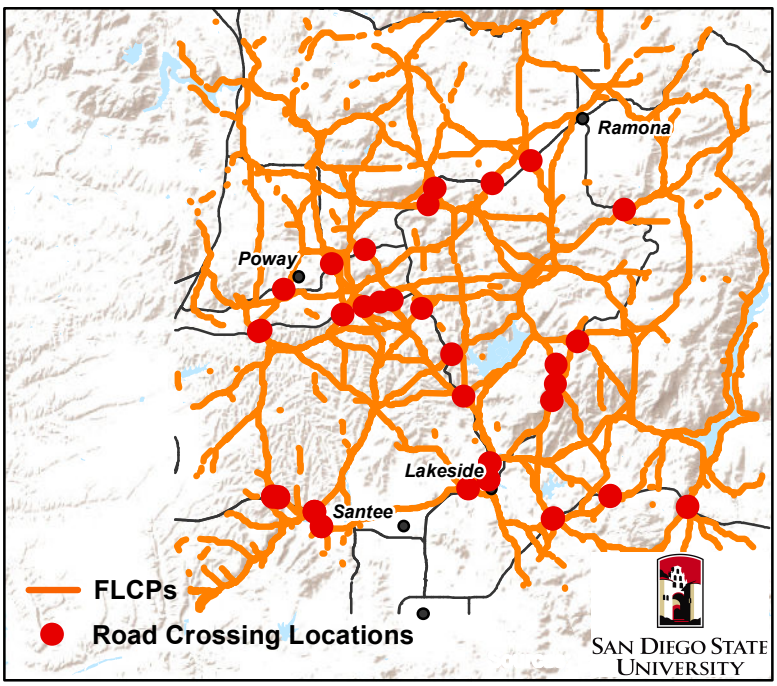
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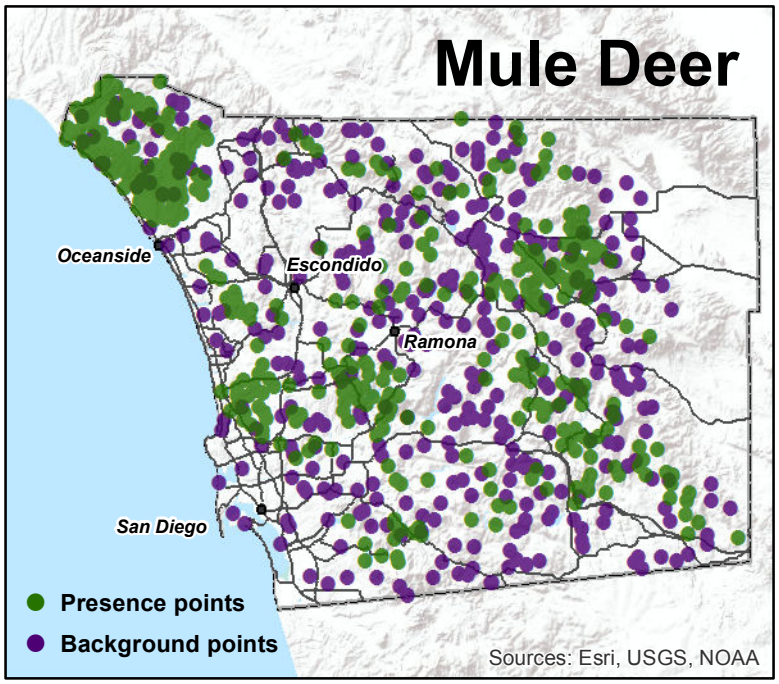
Mule Deer
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San Diego
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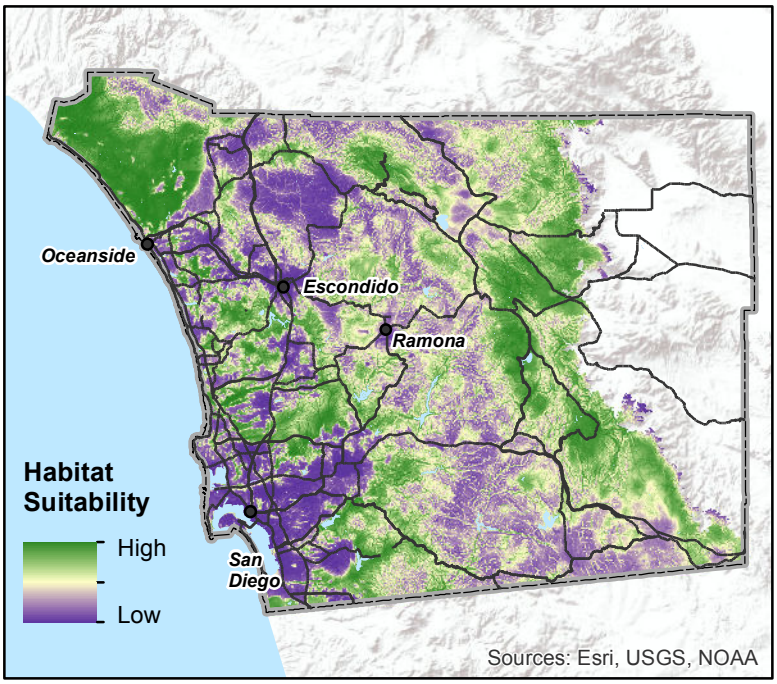
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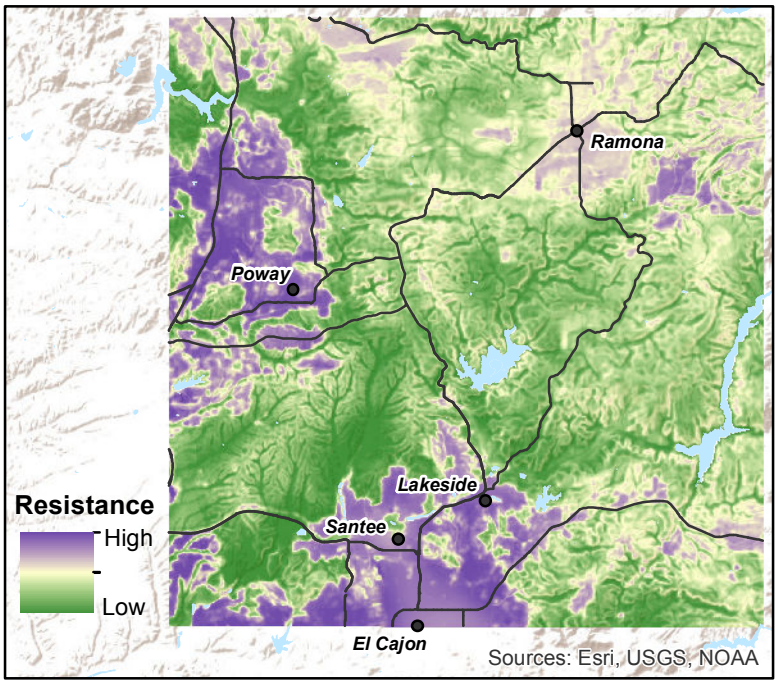
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Santee
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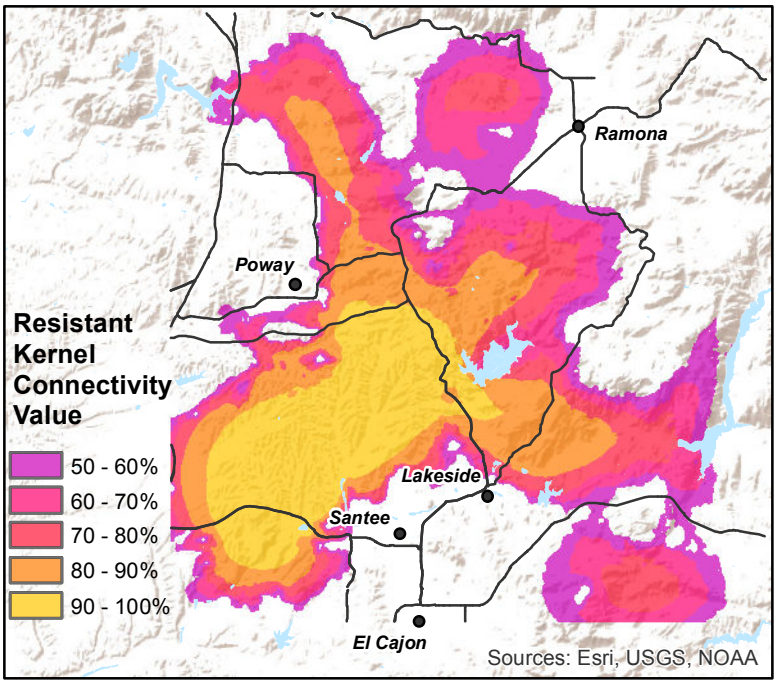
Sources: Esri, USGS, NOAA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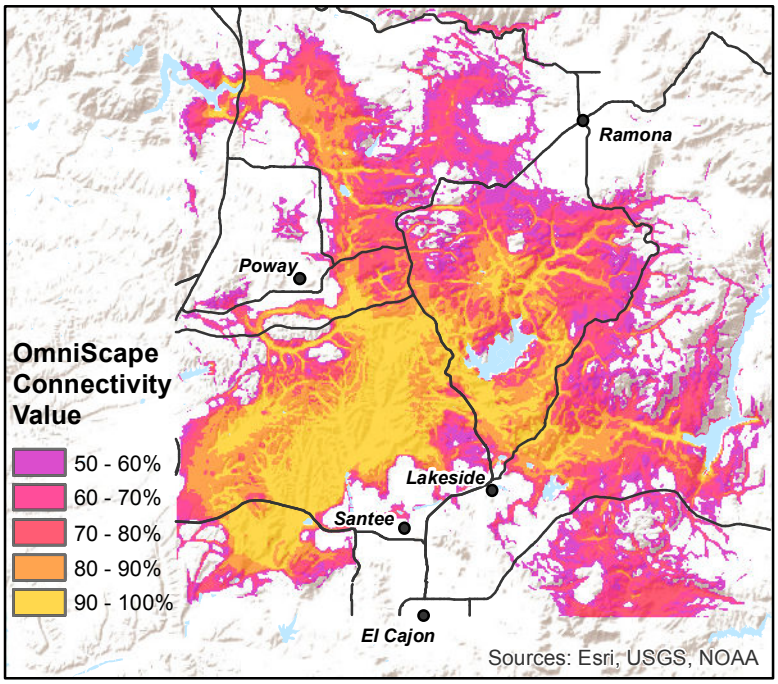
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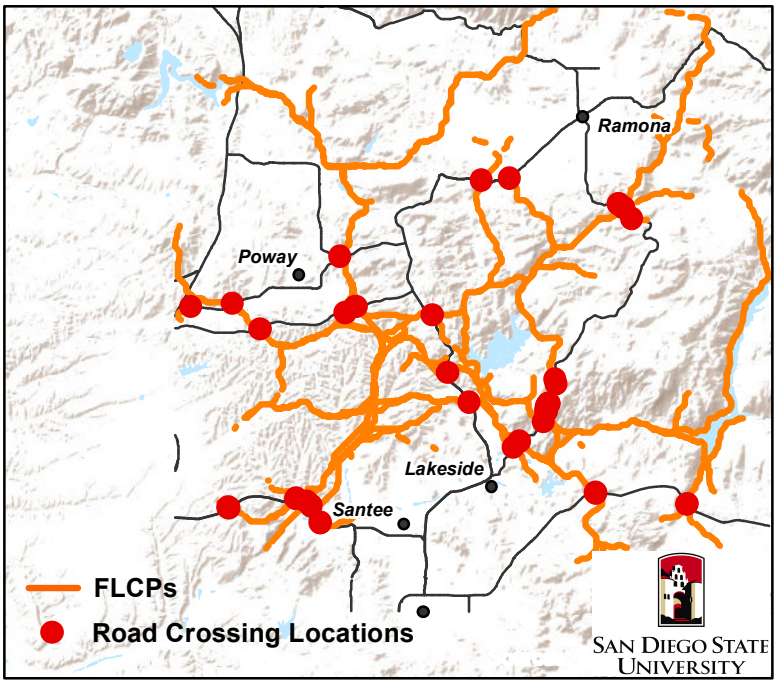
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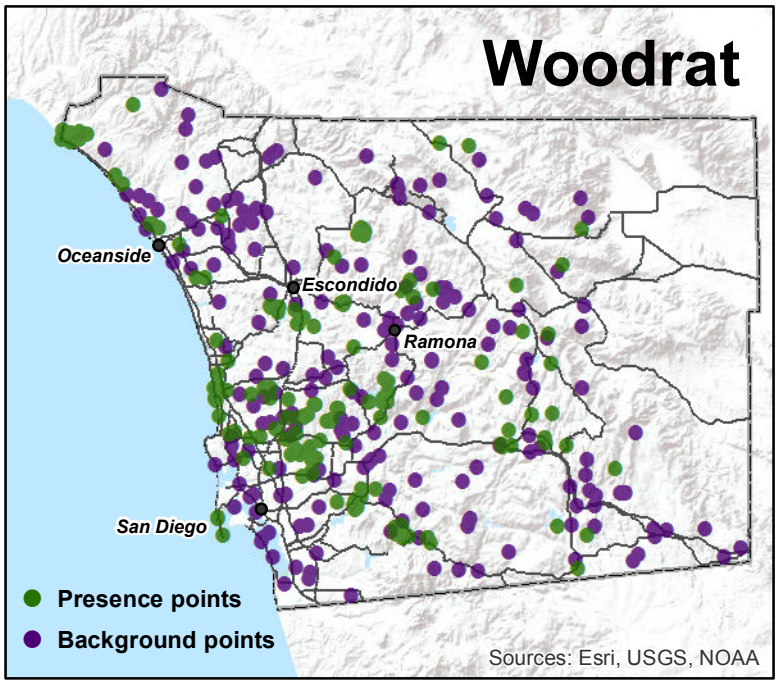
San Diego State University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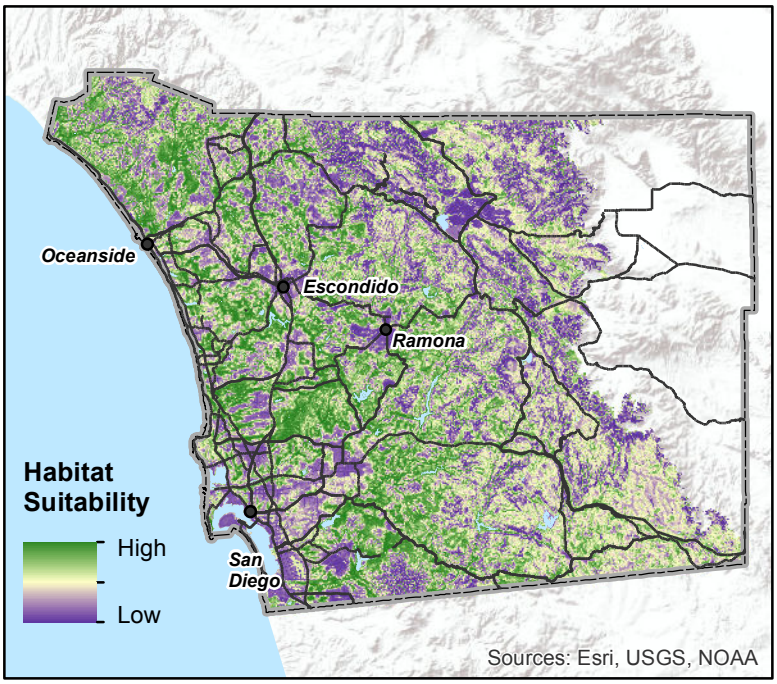
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Ramona
San Diego
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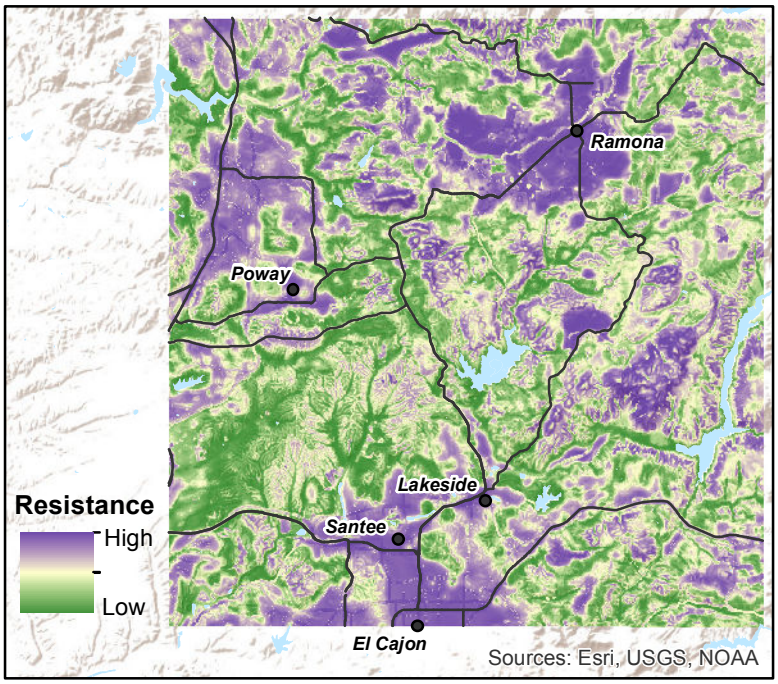
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Santee
El Cajon
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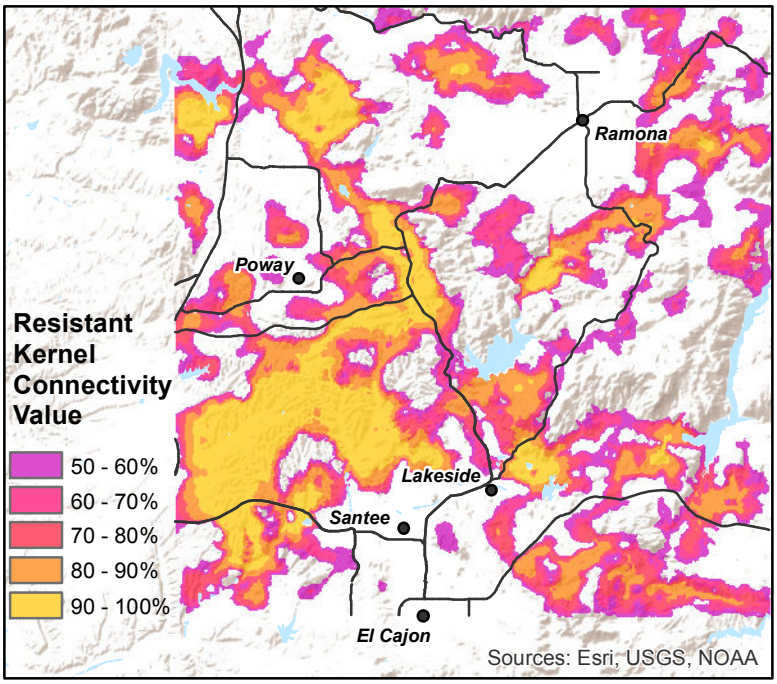
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El Cajon
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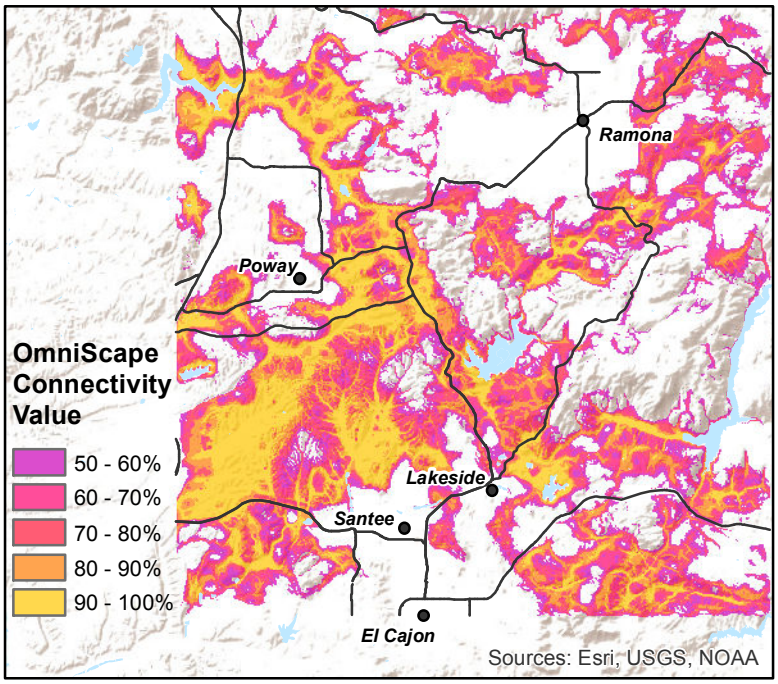
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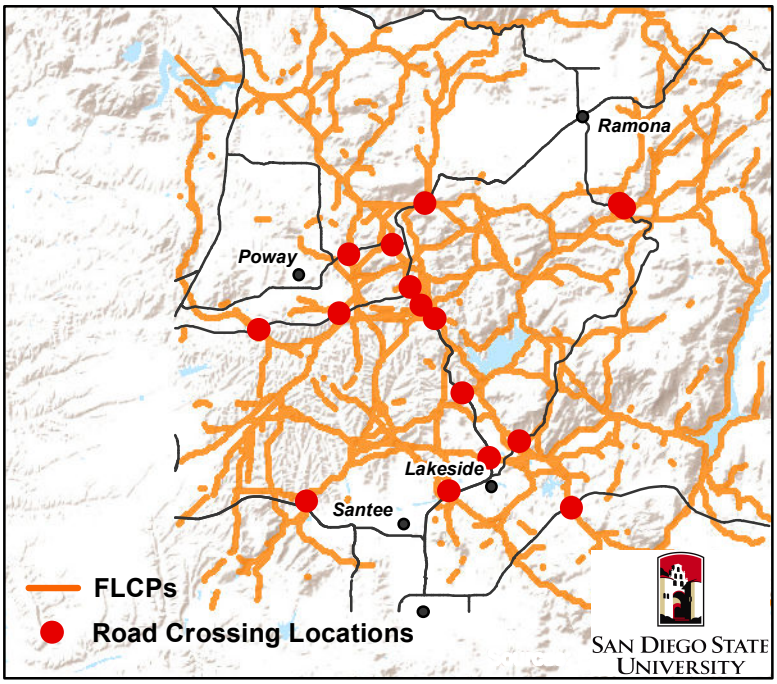
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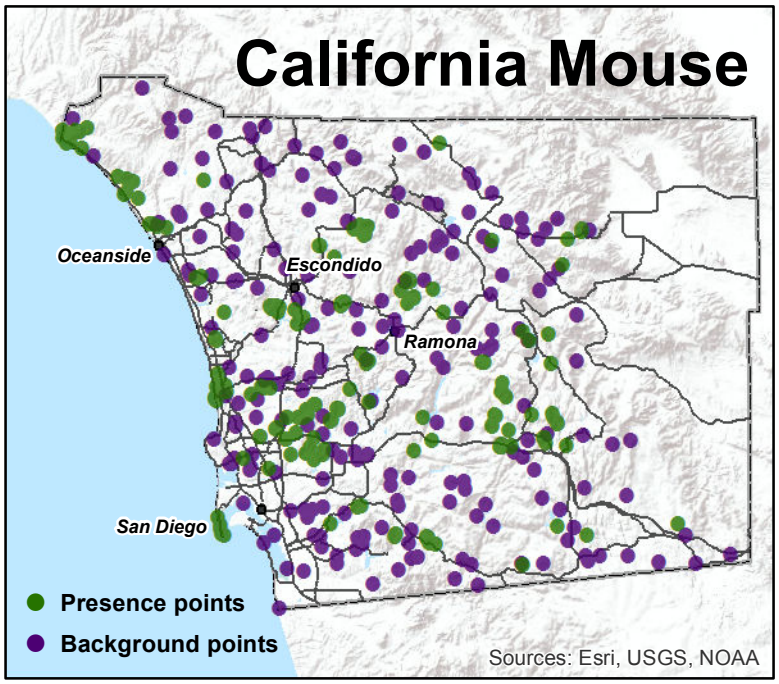
FLCPs
Road Crossing Locations
San Diego State University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Oceanside
Escondido
Ramona
San Diego
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Background points
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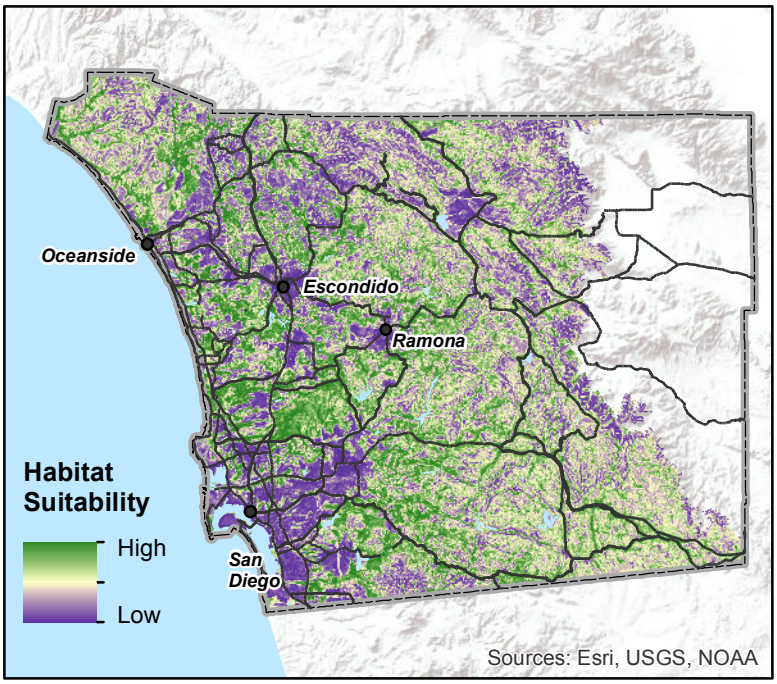
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Escondido
Ramona
San Diego
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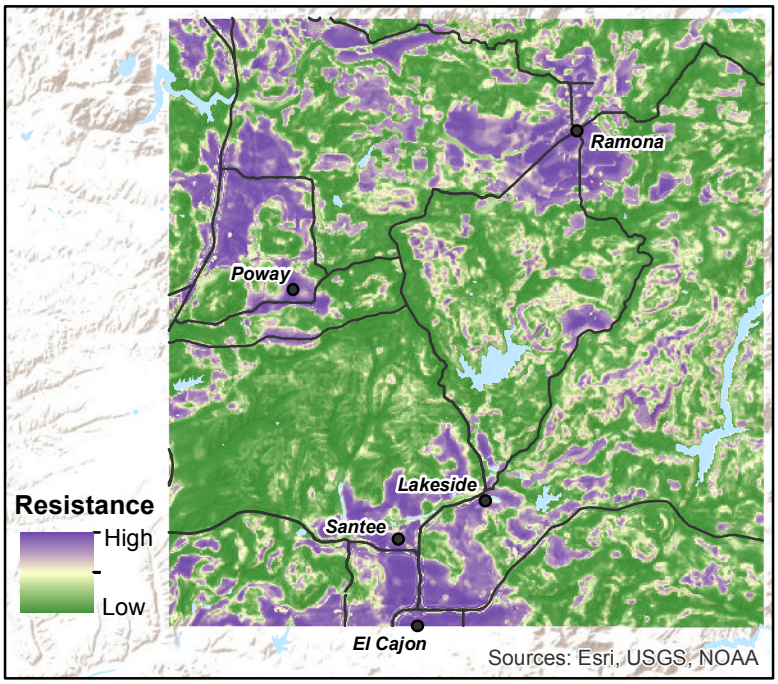
Sources: Esri, USGS, NOAA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Lakeside
Santee
El Cajon
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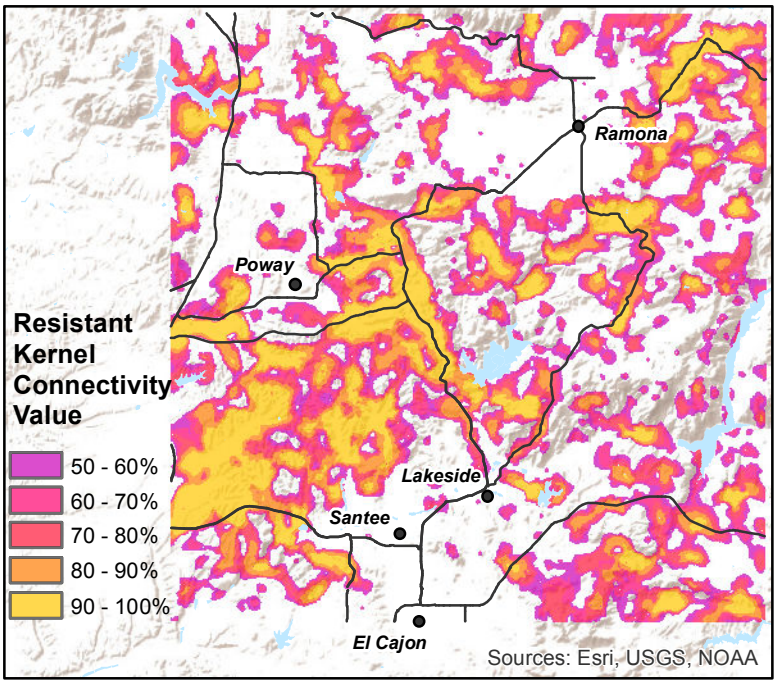
Ramona
Poway
Lakeside
Santee
El Cajon
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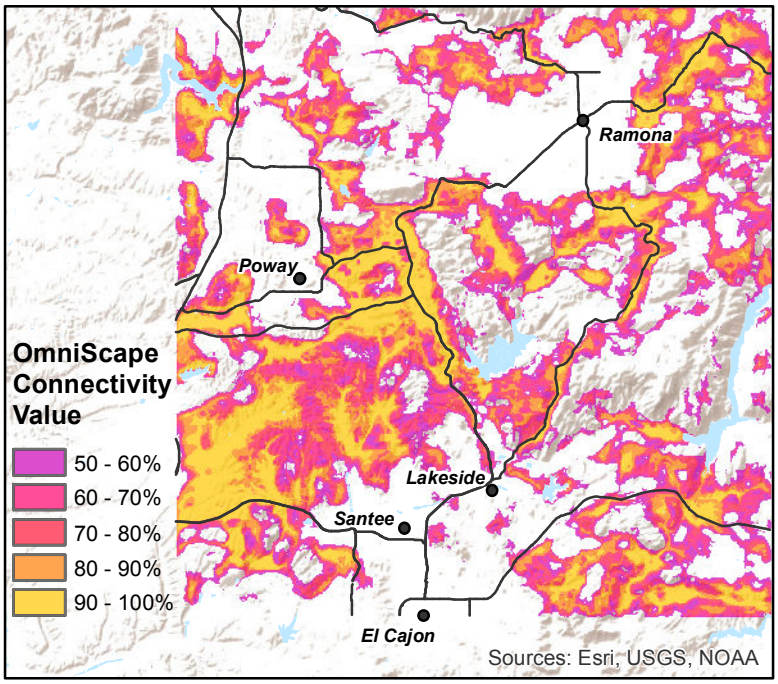
Sources: Esri, USGS, NOAA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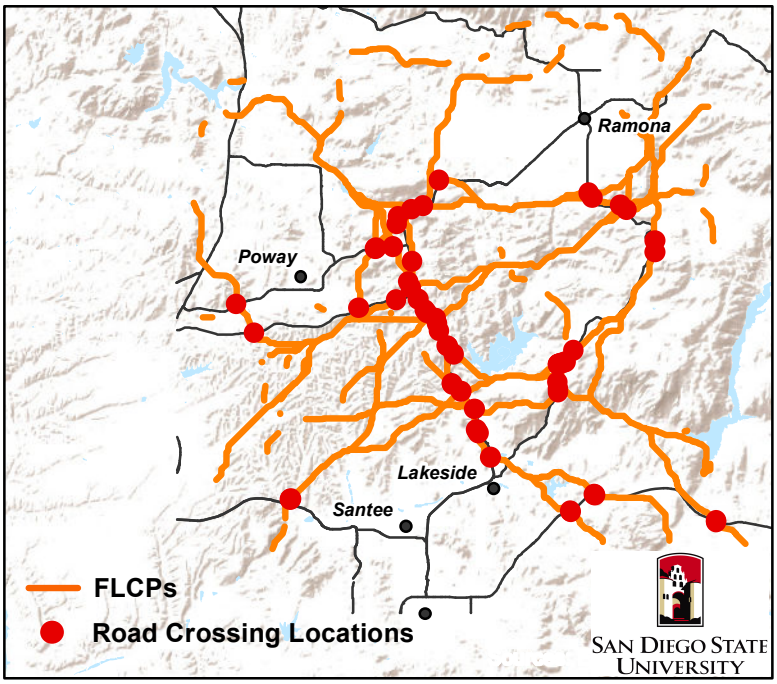
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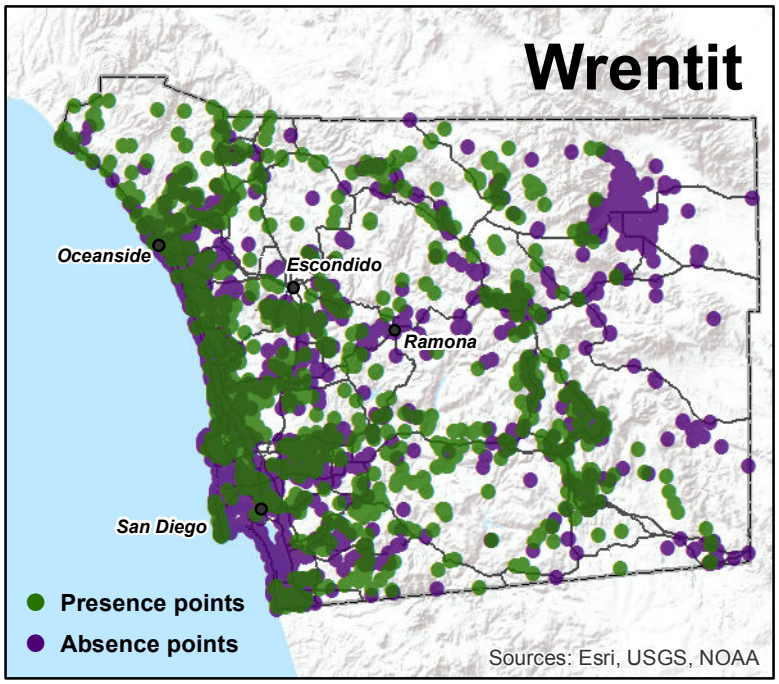
San Diego State University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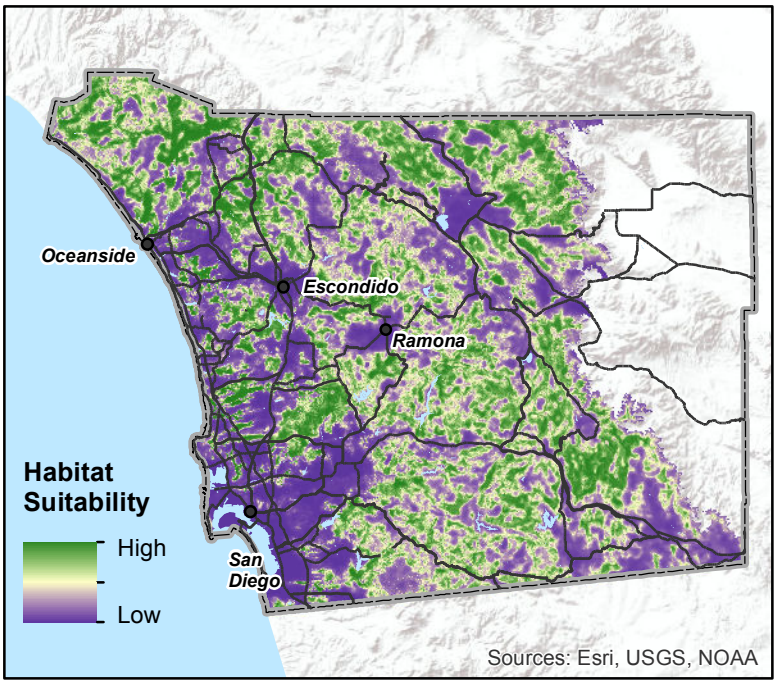
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San Diego
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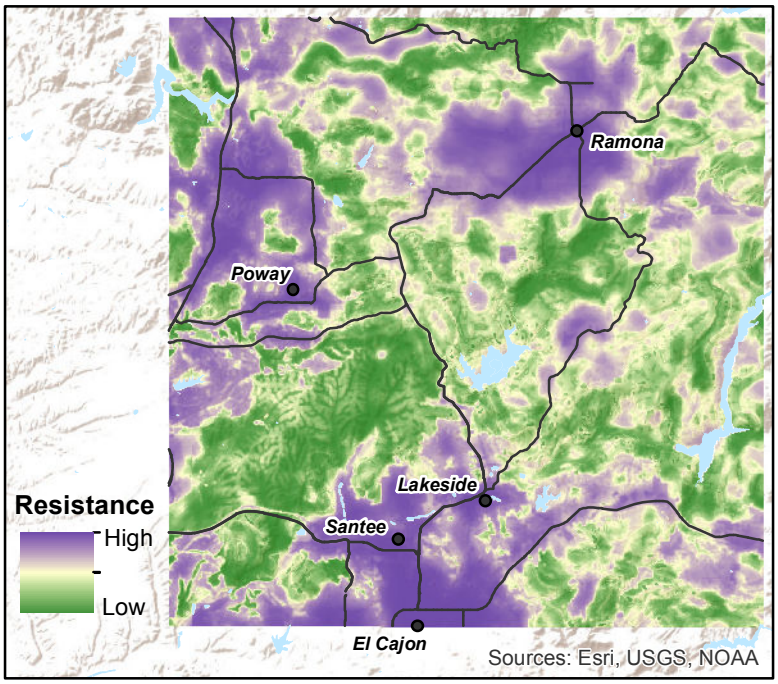
Sources: Esri, USGS, NOAA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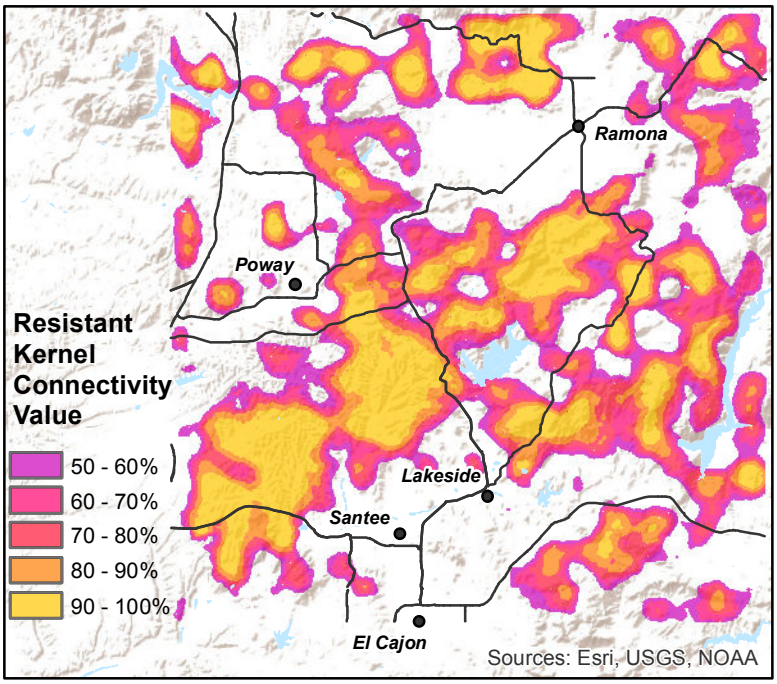
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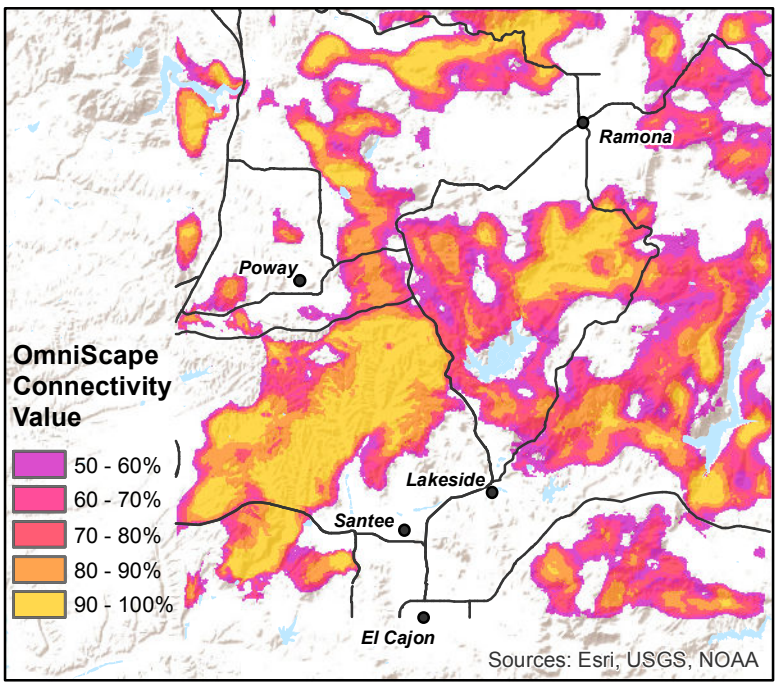
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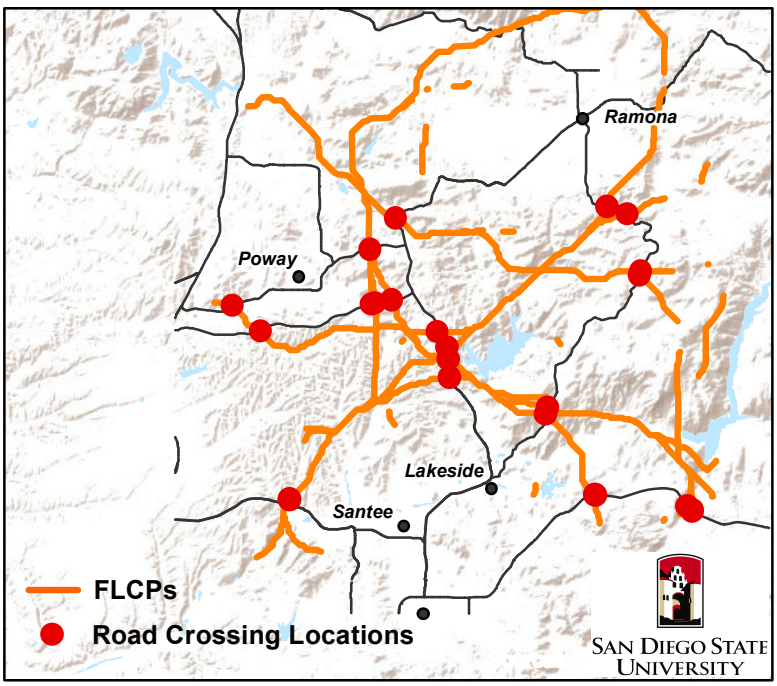
Ramona
Poway
Lakeside
Santee
FLCPs
Road Crossing Locations
San Diego State University

APPENDIX E: LAND FACET MODELING APPROACH

INTRODUCTION

To complement the focal species connectivity modeling approach, we incorporated an approach focused on fixed features of the landscape. To do this, we mapped linkages using a species-blind landscape approach called land facet analysis (Beier and Brost 2010, Brost and Beier 2012), sometimes referred to as physiographic diversity (Theobald *et al.* 2015) or geodiversity (Anderson *et al.* 2015, Comer *et al.* 2015). The idea behind this technique is to conserve nature's stage (Anderson and Ferree 2010, Beier and Brost 2010), by identifying linkages that retain a range of fixed features defined by slope angle, solar insolation, topography, and elevation (Brost and Beier 2012). This method was specifically developed as an approach to connectivity and linkage assessment under climate change that would be robust to the uncertainty in climate data and issues with scale. We incorporated this analysis into our connectivity planning to evaluate the long-term resilience of the corridors we had developed using focal species, and to identify any gaps in our corridor identification that may have arisen from our selection of focal species. Each corridor was designed to retain the attributes of the landscape necessary to facilitate wildlife movement, including a variety of features that encompass the needs of many species ranging from gentle slopes and valleys to rugged terrain and ridges (Jenness *et al.* 2010).

METHODS

To execute the land facet modeling, we used the Land Facet Corridor Designer (Jenness *et al.* 2010) toolbox in ArcGIS. We input topographic data from a 30 m digital elevation model to develop unique land facets across our study. We then modeled corridors for each of those land facets, based on the concepts of resistance and least-cost modeling, to identify pathways for movement along those facets.

From the initial digital elevation model, we generated three additional variables that we used to identify land facets in our study region: 1) slope, 2) solar insolation, and 3) a slope position surface categorized into four classes – canyons, gentle slopes, steep slopes, and ridges. Once we identified these original variables, we followed the procedures outlined by Jenness *et al.* (2010). We populated the values for elevation, slope, and insolation at each grid cell for our four slope position classes. We then exported the data for each of these four classes into R to conduct a cluster analysis based on the variables for each slope position class. To identify clusters, we performed a kernel density analysis, identified and excluded values that were outliers, and used fuzzy c-means clustering to classify the pixels into groups. Based on these data outputs, we then selected the number of clusters, or individual facets, for each slope position class that we would use for the remainder of the analysis.

We imported our cluster values back into ArcGIS and used them to generate a land facet raster for each slope position class. Using the *Calculate Density Surface* tool in the Land Facet Corridor Designer toolbox, we identified the areas of greatest density of each of the new land facet classes. That output was then used to generate termini polygons of the areas of greatest density of each land facet within our wildland blocks of interest. We also used the land facet density surface to create a Mahalanobis distance raster for each class of the land facet raster to be used in our corridor modeling as the equivalent of resistance. To standardize the scale of the Mahalanobis distance raster, we used the *Chi Square Raster Transform* tool. This creates a "resistance" or "distance" surface (on a 0 to 1 scale) to use in our corridor modeling where cells

with a greater distance (closer to 1) from an area of high density of the land facet of interest have a higher resistance value. Finally, because the surfaces created thus far only include topographic variables and have not incorporated any other landscape features that may affect wildlife movement, we clipped this resistance layer using an urban raster mask generated from the SANDAG Current Land Use layer (SANDAG 2016) to exclude urban areas from our corridor modeling.

We used Linkage Mapper (McRae and Kavanagh 2011) to generate least cost corridors using the Mahalanobis distance surfaces as our resistance inputs and the termini polygons of high land facet density within blocks of preserved lands as our target core areas to connect. This process generated raster corridor surfaces that can then be truncated to identify corridor extent. We selected cutoff values for each land facet raster that produced a contiguous corridor but was not too wide or expansive. Finally, we converted our raster surfaces to corridor shapefiles which we then cleaned and filled to remove narrow corridor segments and artifacts from the modeling process both manually and using the *Fill holes in corridor* script in the Corridor Designer toolbox for ArcGIS (Majka *et al.* 2007) to fill holes less than 500 m in diameter.

We examined the final land facet corridors to identify unique corridors that had not been captured by our multi-species. We also compared our final land facet corridors for each topographic position class to our focal species corridors to determine how well our focal species corridors had captured land facet corridors of each class.

RESULTS

Our analysis of land facets resulted in the identification of 14 total facets, three types for canyons and four each for gentle slopes, steep slopes, and ridges (Table E1). We generated least cost corridor connectivity rasters for each of the 14 facets and truncated them at values ranging from 500 to 2,500 to define distinct corridors. After cleaning and filling the initial corridor polygons, we compared these land facet corridors to our focal species corridors. We found that there were three sections of land facet corridors that had not been captured by our focal species corridors: 1) at the northern boundary of the study area in San Pasqual Valley, there was land facet category LF2d corridor; 2) on the eastern boundary of the study extent along the ridgelines that connect Rock Mountain and El Cajon Mountain, we identified a corridor for land facet category LF4d; and 3) through the Ramona Grasslands, was a land facet type LF2c corridor. It is likely that the two land facet corridors near the boundaries of our analysis area were not captured in our focal species corridors due to edge effects during modeling rather than a lack of suitability of the habitat features. As such, we opted not to add those corridors to the connectivity plan for the region. In contrast, the grasslands corridor (LF2c) was located in a region towards the center of our analysis area that was likely not incorporated into our focal species corridors because we had not explicitly chosen a grassland-associate in our suite of focal species. Therefore, we opted to add the LF2c corridor through the Ramona Grasslands to our final corridor design.

Table E1. Land facets identified across the SR-67 study area

Land Facet Category	Topographic Position	Slope	Insolation	Elevation
LF1a	Canyons	gentle	warm	low
LF1b	Canyons	moderate	hot	high
LF1c	Canyons	steep	cool	mid
LF2a	Gentle slopes	gentle	warm	low
LF2b	Gentle slopes	moderate	warm	high
LF2c	Gentle slopes	steep	hot	mid
LF2d	Gentle slopes	steep	cool	mid
LF3a	Steep slopes	gentle	hot	high
LF3b	Steep slopes	gentle	warm	low
LF3c	Steep slopes	steep	hot	mid
LF3d	Steep slopes	moderate	cool	mid
LF4a	Ridges	gentle	warm	low
LF4b	Ridges	moderate	hot	high
LF4c	Ridges	steep	hot	mid
LF4d	Ridges	steep	cool	mid

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APPENDIX F: SR-67 CONNECTIVITY PLANNING STAKEHOLDER ENGAGEMENT PROCESS

A key component to the development of the geospatial and data products we produced for this project was stakeholder engagement. In order to create a connectivity plan that would be implemented and used in decision-making processes for conservation management and planning efforts, we solicited input from a targeted group of stakeholders at various stages of this project (Table F1). Through these engagement sessions, we gathered information that allowed us to create actionable science and decision support tools that would allow end users to integrate the SR-67 connectivity implementation plan into ongoing efforts.

Our identification of relevant stakeholders began prior to the outset of this project, in September of 2014. We convened a meeting to share information with key stakeholders who had either collected data in and around SR-67, or had specific management and purchase interests in the project vicinity. The meeting was attended by 17 stakeholders from 9 organizations which included agency representatives, conservation planners, and wildlife researchers. The group exchanged information, identified data resources and information gaps, and prioritized conservation action in the vicinity of SR-67. One of the priorities was furthering connectivity planning for the region and the group discussed options and opportunities for analysis that allowed us to refine our proposal for this project. In addition, we gathered information from meeting participants about datasets available for the greater SR-67 area that could be used for future analyses of connectivity for a broad suite of species. In total, we identified nine research efforts, in addition to San Diego State University's ongoing research on SR-67 crossings for Caltrans, which could be synthesized in a comprehensive connectivity plan.

Once we officially kicked off the SR-67 Multi-species Connectivity Planning Project in March 2016, we broadened our stakeholder outreach, eventually contacting 55 stakeholders from 19 organizations (Table E1). Our outreach and engagement sessions included three types of meeting formats: 1) full stakeholder meetings for all interested parties, 2) focused engagement sessions with small groups of experts in planning and management, and 3) one-on-one sessions with individual researchers or species experts. During the project period, we convened three stakeholder meetings of our full group, three focused engagement sessions with small groups, and numerous feedback sessions with experts at several stages of the project. The agendas, notes, and attendee lists from these meetings are included at the end of this Appendix.

Our full stakeholder meetings were structured around the two phases of the project. On April 27, 2016, we convened an initial stakeholder coordination meeting to invite input on project considerations and gather information on all possible data sources that could be incorporated into our analysis. We followed up on this meeting with one-on-one interactions with several researchers and data holders[1] to access data, investigate limitations and nuances of the data, and discuss selection of the most appropriate focal species. Once we had completed initial modeling

[1] Sheilla Alvarez, Barona Band of Mission Indians; Randy Botta, CDFW; Cheryl Brehme, USGS; Van Butsic, UC Berkeley; Robert Fisher, USGS; Anna Mittleberg, USGS; Kris Preston, SDMMP and USGS; Carlton Rochester, USGS; Drew Stokes, SDNHM; Scott Tremor, SDNHM, Amy Vandergast, USGS; Winston Vickers, UC Davis

for our focal species, we presented our species-specific habitat and movement models, resistance surfaces, and initial corridor modeling (Appendices C and D) in a second stakeholder meeting on February 15, 2017. At this session, we were able to share our modeling methodology with project stakeholders, receive feedback on our products and presentation of them, and discuss additional data attribution for our final corridor and crossing structure plan. Based on the feedback we received at this meeting, we were able to make several decisions regarding our process for finalizing corridors with greater confidence after discussing data limitations and concerns with stakeholders. This was a critical step in the process that allowed end users to understand the issues we faced with combining multiple data sources and provided an opportunity for transparency in our scientific process and modeling decision-making.

Our final meeting, on June 2, 2017, focused on the Phase II products we developed for end users. We presented our refined and attributed multi-species corridor and crossing structure recommendations, a decision support tool, and road crossing implementation options to stakeholders. We gathered input in final refinements and presentation aspects as well as final data delivery from stakeholders during this session. In preparation for this final meeting, we convened three separate focused engagement sessions to solicit input from small groups of experts to refine our products prior to rolling them out to our full stakeholder group. On May 12, 2017, we presented our multi-species corridor and the associated decision support tool to planning and management experts from the US Fish and Wildlife Service, California Department of Fish and Wildlife, San Diego Management and Monitoring Program, Endangered Habitats League, and The Nature Conservancy. We refined our presentation and messaging of our products based on input from this meeting. On May 18, 2017, we gathered with environmental and planning specialists at Caltrans to gather input on our road crossing structure recommendations. During that session, we received suggestions to refine our recommendations for crossing structures and best management practices. We also determined that prioritization of the structures by importance to wildlife and feasibility of implementation would be of value to Caltrans in their planning and funding process. We held one additional focused outreach session for partners from the County of San Diego. As a result of staffing changes during the course of this project, there had not been consistent participation at all stakeholder engagement sessions by County representatives, particularly from the Department of Parks and Recreation. To bring new management staff up to date and gather additional input, we held one additional project overview meeting at the County offices on May 23, 2017.

At our June 2, 2017 stakeholder meeting, there was discussion about carrying forward our data products into a refined conservation strategy for the project area based on the analyses we completed. Stakeholders were interested in developing a comprehensive plan that could be executed by a range of land managers using the decision support and scoring tool that resulted from this project. To advance that planning, we have suggested the multijurisdictional coordination take place in a workshop format and have offered to provide input and guidance on adapting and using the decision support tool in that planning and decision-making process.

Table F1. SR-67 Stakeholders and organizational affiliations. Each stakeholder's engagement during the process is listed according to their attendance at the three main meetings as well as other types of interactions during the project

Name	Organization	April 27 Mtg	Feb 15 Mtg	June 2 Mtg	Other engagement
Jim Whalen	Alliance for Habitat Conservation	N	N	N	Asked Brock Ortega to attend on his behalf
Sheilla Alvarez	Barona Band of Mission Indians	N	N	N	One-on-one consultation
Carol Williams	California Department of Fish and Wildlife	N	N	Y	
Dave Mayer	California Department of Fish and Wildlife	N	Y	Y	Attended 12May2017 meeting
Gail Sevrens	California Department of Fish and Wildlife	N	N	Y	
Hans Sin	California Department of Fish and Wildlife	N	Y	Y	
Jason Price	California Department of Fish and Wildlife	Y	Y	N	
Paul Schlitt	California Department of Fish and Wildlife	Y	N	N	
Randy Botta	California Department of Fish and Wildlife	N	N	N	One-on-one consultation
Randy Rodriguez	California Department of Fish and Wildlife	N	N	N	
Rich Burg	California Department of Fish and Wildlife	Y	N	N	
Simona Altman	California Department of Fish and Wildlife	N	Y	Y	
Tim Dillingham	California Department of Fish and Wildlife	Y	Y	N	
Udara Abeysekera	California Department of Fish and Wildlife	N	Y	Y	
Bruce April	Caltrans	Y	N	N	Attended Caltrans meeting 18May2017
Carl Savage	Caltrans	N	N	N	Attended Caltrans meeting 18May2017
Kim Smith	Caltrans	N	Y	N	Attended Caltrans meeting 18May2017

Name	Organization	April 27 Mtg	Feb 15 Mtg	June 2 Mtg	Other engagement
Markus Spiegelberg	Center for Natural Lands Management	N	Y	N	
Jim Lyon	City of Poway (retired)	Y	N	N	
Jerre Stallcup	Conservation Biology Institute	N	N	N	
Abby Zakharin	County of San Diego	N	N	N	Attended County meeting 23May2017
Andy Quinn	County of San Diego	N	N	N	Attended County meeting 23May2017
Christine Sloane	County of San Diego	Y	N	N	
Deborah Mosley	County of San Diego	N	N	N	Attended County meeting 23May2017
Jennifer Price	County of San Diego	Y	N	N	Attended County meeting 23May2017
Kimberly Davis	County of San Diego	Y	N	N	
Leanne Carmichael	County of San Diego	N	N	N	Attended County meeting 23May2017
Lorrie Bradley	County of San Diego	N	N	N	Attended County meeting 23May2017
Marcus Lubich	County of San Diego	N	N	N	Attended County meeting 23May2017
Mary Niez	County of San Diego	Y	Y	Y	
Maryanne Vancio	County of San Diego	Y	N	N	
Melanie Tylke	County of San Diego	N	Y	N	Attended County meeting 23May2017
Susan Harris	County of San Diego	N	N	N	
Brock Ortega	Dudek	N	Y	N	
Michael Beck	Endangered Habitats League	Y	Y	Y	Attended 12May2017 meeting
Keith Greer	SANDAG	N	N	N	
Emily Perkins	SDMMP	Y	N	N	
Kris Preston	SDMMP	Y	Y	Y	Attended 12May2017 meeting, one-on-one consultation
Sarah McCutcheon	SDMMP	N	Y	N	
Yvonne Moore	SDMMP	N	N	N	Attended County meeting 23May2017
Drew Stokes	San Diego Natural History Museum	N	N	N	One-on-one consultation

Name	Organization	April 27 Mtg	Feb 15 Mtg	June 2 Mtg	Other engagement
Scott Tremor	San Diego Natural History Museum	N	N	N	One-on-one consultation
Becca Lewison	San Diego State University	Y	Y	Y	
Kathy Zeller	San Diego State University	Y	Y	Y	
Megan Jennings	San Diego State University	Y	Y	Y	
Cara Lacey	The Nature Conservancy	N	N	N	Attended 12May2017 meeting
Trish Smith	The Nature Conservancy	N	Y	Y	
Winston Vickers	University of California, Davis	Y	N	N	One-on-one consultation
Sally Brown	US Fish and Wildlife Service	Y	Y	Y	
Susan Wynn	US Fish and Wildlife Service	Y	Y	Y	Attended 12May2017 meeting
Amy Vandergast	US Geological Survey	Y	Y	Y	One-on-one consultation
Carlton Rochester	US Geological Survey	N	N	Y	One-on-one consultation
Cheryl Brehme	US Geological Survey	Y	N	Y	One-on-one consultation
Robert Fisher	US Geological Survey	Y	N	Y	One-on-one consultation
Barry Martin	Wildlife Tracking Company	Y	N	N	

Stakeholder Meeting Agendas and Notes

Highway 67 Connectivity Informational Meeting
27 April 2016
1:00 PM – 3:00 PM
USGS Conference Room
4165 Spruance Rd, San Diego, CA 92101
Contact: Megan Jennings / 760.214.2145 (mobile) / mjennings@mail.sdsu.edu

Agenda

Item	Time*	Activity	Responsibility
1.	1:00	Introductions of Participants Review Purpose, Overview, and Objectives	Conveners
2.	1:10	Presentation on Previous SR-67 Wildlife Crossing Study - Purpose - Findings	Megan Jennings
3.	1:35	Overview of SR-67 Regional Connectivity Planning Project - Goals & Objectives - Approach	Megan Jennings SDMMP
4.	1:45	Review of Data to be Incorporated into Connectivity Assessment - Table of projects - What's missing?	All
5.	2:00	*Break*	
6.	2:10	Approach for Prioritization - Stakeholder review - Input on data layers to include – e.g., zoning, General Plans, PAMA	All
7.	2:30	Acquisition Updates - New purchases - Recreational trail connection and tunnel/bridge - Prior acquisition prioritization work?	All
8.	2:50	Recap and Moving Forward - Review of stakeholder engagement plan for remainder of project	All
9.	3:00	*Adjourn*	

WebEx: https://usgs.webex.com/usgs/j.php?MTID =maebd4ac48f77043d06c450d42c78d657
Meeting number: 719 588 909
Audio: Dial toll free 855-547-8255
Conference Security Code 59808841#

Highway 67 Connectivity Stakeholder Meeting Notes
27 April 2016
1:00 PM – 3:00 PM
USGS Conference Room
4165 Spruance Rd, San Diego, CA 92101
Contact: Megan Jennings / 760.214.2145 (mobile) / mjennings@mail.sdsu.edu

MEETING TASK LIST

*Note – Please contact Megan by June 1 with input on any additional species data you would think we should review or you would like to see included in the analysis

Action Item	Lead/Participants	Timeframe
Continue thinking about considerations for prioritization (see those already captured below)	ALL	By Fall 2016
Consider additional stakeholders to engage	ALL	Get names/contacts to Megan by June 2016 – update as needed
Share available data on species and other relevant information	Emily Perkins	DONE
Provide Wildcat Canyon reports and any prior parcel prioritization work from Section 6 info	Susan Wynn and Megan Jennings to connect on this	June 2016
Update conserved lands layer in project maps	Megan Jennings	DONE
Meet with USGS to discuss additional data to be included and application of individual-based models to assist with assessment	Megan Jennings Robert Fisher Carlton Rochester Jeff Tracey Amy Vandergast	May 2016
Revise data list with additional sources and identify key focal species	Megan Jennings	May 2016 (Updated once – final update after more data/species review)
Share final focal species list with SDMMP and stakeholders	Megan Jennings	June 2016

MEETING NOTES

1) Presentation on Previous SR-67 Wildlife Crossing Study
   a) Purpose: To inform proposed median barrier safety project and begin collecting more recent data to inform eventual plan for widening of highway
      i) Caltrans is moving forward with centerline traffic channelizers only, no concrete or tension barrier
   b) Findings:

   i) Several roadkill hotspots identified: Mt. Woodson is largest and most severe; sections between Poway Rd and Scripps Poway Pkwy and the Lakeside Grade are secondary hotspots.
   ii) Comparison with regional data shows some evidence that the road is a barrier for some species (e.g. bobcats)
   iii) Used crossing data from SR-67 project and SDSU's 2011-2012 connectivity study to identify features of both the structures and the surrounding environment that are associated with the highest crossing rates. Can use those to identify site specific placement and design of structures in wildlife crossing infrastructure plan

2) Overview of SR-67 Regional Connectivity Planning Project
   a) New work builds on previous project but in an expanded area to identify linkages between core areas in the vicinity of SR-67 to connect linkages and design crossing structures where linkages meet the road. (Study area map included – should cover new Lakeside acquisitions, Santee subarea plan, and Wildcat Canyon Road, another road with wildlife crossing issues)
   b) Meets MSP target of addressing connectivity surrounding SR-67 and planning for eventual widening
   c) Although Caltrans does not have widening scheduled until ~2040, new SANDAG initiative may move forward and would include transportation funding, which would likely result in SR-67 improvement on a shorter time frame.
   d) Leveraging investment in prior data collection and conducting a data synthesis to model connectivity
   e) Using analyses appropriate to data sources. Will include an assessment of habitat suitability across a wider region (which could also benefit things like the North County Plan)
   f) Deliverables
      i) Linkage plan with maps
      ii) Prioritization of implementation actions to complete linkages (land acquisitions, habitat enhancement/restoration)
      iii) Infrastructure plan – this will include specific siting recommendations along with structure type. There will be several options for each crossing so when a feasibility assessment is conducted by transportation engineers, they have options if our top recommendations cannot be implemented.

3) Review of Data to be Incorporated into Connectivity Assessment
   a) Table of data
      i) revised data table attached
   b) What's missing?
      i) Information from Wildcat Canyon Road – Susan Wynn has hard copies?
      ii) Comparison with CBI data from early 2000s
      iii) USGS genetics data (herps)
      iv) USGS species distribution models for herps
   c) Suggestion to list data by focal species and perhaps identify which species are riparian vs. upland movers
   d) How are species in list related to existing MSCP plans?
      i) The focal species we list are included in the Connectivity Monitoring Strategic Plan as priority focal species for connectivity. Some are not included, but for those, we lack adequate data to model connectivity at this time.
   e) How to include data from other species of interest, e.g. how to get arroyo toads across the road at Santa Maria Creek or how to account for small mammal movements
      i) Can use species occurrences or expert opinion in prioritization phase to validate linkages and ensure we are providing connectivity for all species even those that are not modeled (e.g., arroyo toad, badger, ringtail)

4) Approach for prioritization
   a) Stakeholder review
   b) Who else do we need to include?

i) Jim Whalen – To connect on the Santee Subarea plan
ii) City of San Diego representative?
iii) Ramona planning group engagement?
iv) Barona Band of Mission Indians representative?
v) County of San Diego public works representative (information on surrounding roads?)

c) Input on data layers to include
i) Biological prioritization: union of all focal species and the more focal species covered, the higher the ranking of a linkage; can also include other species data like species distribution models and occurrence records to consider not-target species
ii) Preserve status – core or non-core, intactness(?), human activity level and type
iii) Filter of undeveloped areas that are not currently conserved
iv) Vegetation data (AECom vegetation layers)
v) County land-use data – General Plan 2020 Zoning plans (how to address parcel owners requesting variances?)
vi) Other data on growth – urban growth models (UPlan or Spatially Explicit Regional Growth Model)
vii) APNs

5) Acquisition updates
a) New purchases
i) EHC acquisition of Lakeside Downs and Lakeside Ranch
ii) 120 acres acquired and coordinating acquisition of another 300 acres between Iron Mtn and Dos Picos Park
iii) County acquisitions of 200 acres between Poway Road and Scripps Poway Parkway and 750 acres north of Boulder Oaks

b) Recreational trail connection and tunnel/bridge – Jim Lyon and County have loose contact with Jim Hagy. Need to keep in communication to ensure any trail and crossing structure planning have wildlife as primary planning consideration for structure placement and design

c) Prior acquisition prioritization work – some of this work was done in prior meeting, data has been used in Section 6 work

6) Next steps
a) The next items for stakeholder review will be sent electronically in early/mid summer 2016
b) We plan to request a technical review from researchers/data collectors in fall 2016
c) A full stakeholder review during a convened meeting/workshop in winter 2016-2017

Highway 67 Connectivity Meeting Agenda
Species Corridor Review
15 February 2017
9:00 AM – 12:00 PM
USGS Conference Room
4165 Spruance Rd, San Diego, CA 92101
Contact: Megan Jennings / 760.214.2145 (mobile) / mjennings@mail.sdsu.edu

Objective: To review draft data products for the SR-67 Connectivity Planning Project and solicit stakeholder input. These products include habitat suitability maps for focal species and initial corridor maps. We will also discuss next steps in the analysis and planning for this project.

1. Welcome and introductions
2. Review purpose, overview, and objectives
3. Presentation on current project status, data analysis, and map products to be reviewed
4. Input on map products
   General questions/comments
   Break out groups
5. Next steps and additional data inputs
6. Plans for additional stakeholder input

Join from PC, Mac, Linux, iOS or Android: https://SDSU.zoom.us/j/978735315

Or iPhone one-tap (US Toll): +16465588656, 978735315# or
+14086380968, 978735315#

Or Telephone:
Dial: +1 646 558 8656 (US Toll) or +1 408 638 0968 (US Toll)
Meeting ID: 978 735 315

SR-67 Connectivity Assessment Meeting Notes
Draft Corridor Map Review Session
15 February 2017
9 AM – 12 PM

Meeting Conveners: Megan Jennings, Kathy Zeller, and Rebecca Lewison

Attendees:

Udara Abeysekera, CDFW	David Mayer, CDFW	Susan Wynn, USFWS
Amber Pairis, CDFW	Melanie Tylke, County Parks	Tim Dillingham, CDFW
Amy Vandergast, USGS	Mary Niez, County Parks	Hans Sin, CDFW
Sally Brown, USFWS	Kris Preston, SDMMP	Eric Hollenbeck, CDFW
Markus Spiegelberg, CNLM	Sarah McCutcheon, SDMMP	Simona Altman, CDFW
Kim Smith, Caltrans	Trish Smith, TNC	Brock Ortega, Dudek
Jason Price, CDFW	Michael Beck, EHL	

Meeting Objective: To provide an overview of the methods applied thus far in the development of corridor maps and to review those outputs for our target focal species identified in the first stakeholder meeting.

Background and Approaches Applied for Corridor Modeling
Presentation slides have been uploaded to the Google Drive

The basic methods we applied are important to understand before jumping into maps. A summary of the methods and their purpose can also be found in the Google Drive.

General Comments/Questions

1. For initial map/model review we have set up a Google Drive given the sheer number and size of files we need to share. Megan will keep Google drive up to date, so everyone can see changes and updates. NOTE: We did make some updates after the stakeholder meeting.
   Link: https://drive.google.com/open?id=0B3mGLNDMcQ3Dd01jWml6WlA3Nms
2. Focal species selected based on available data, habitat associations, movement behaviors, and how likely it is that focal species movement might be representative of movement for additional species of interest not modeled
3. Can we compare connectivity across species? The way we have displayed the static maps, no. Connectivity is only relevant at the scale of the individual species in this representation although that is something we will consider and account for during prioritization.
4. Confidence in SDMs – habitat suitability surfaces / movement probability surfaces:
   a. All suitability models (except herp models from Franklin et al. 2008) were reviewed by species experts prior to corridor modeling
   b. Deer model likely underpredicts based on limited data - sampling throughout the county was spotty. This was addressed in connectivity models through adjusted resistance scale. Recommend caution in applying deer suitability model in other applications though.
   c. Rodent and wrentit models appear to predict relatively well
5. Herps – There were several limitations in applying the existing SDMs from USGS pitfall trap data developed in Franklin et al. 2008
   a. Of the available species from the Franklin/USGS SDMs, we selected those with good model predictive performance (AUC > 0.75)
   b. From there we chose species with suitable habitat in the study area and dispersal distance that would allow for movement and corridor development
   c. Habitat suitability surfaces were developed at a coarser scale (100m grid cells) than those we generated for this project

d. Unexplained gaps in the suitability surfaces were of concern. We smoothed and filled these to the best of our ability
e. We only received 2 different SDM model outputs, Random Forest and GAM, compared to the 6 we used in our ensemble model development.

General Recommendations

- Use a different color scheme either for the model outputs or for the roads to make them distinct. Recommended both for suitability maps and for corridor maps.
- Provide a short-term, interim plan for road crossing locations to recommend improving what we currently have to work with as well as directional fencing.
- Provide a long-term plan for both road crossing structures and larger landscape connectivity.
- Do not use APNs, but instead just show parcel boundaries and provide geospatial data so users can pull up relevant parcels on their own.
- Remove conserved lands from static connectivity maps to allow a better view of output

Comments from small animal group:

Wrentit

- Best places for birds of this type to cross roads is when there is a hillside on both sides of the road. This is going to be problematic in the Mt. Woodson area since it is a hill on one side but drops off on the other side.
- Other options for crossings are incorporating crossings that have vegetative structure that would be conducive to bird movement.
- Roads area also a barrier to wrentit. Might be useful to look at genetic study done in Santa Monica area (Delaney et al. 2010) to see what types of roads were barriers to wrentit movement.
- The group observed that there isn't a lot of great habitat close to 67 on the east side, which might make successful connectivity difficult.
- Suggestion for connecting east-west movement: 3 crossings points immediately east of San Vicente Reservoir. There's an X with several crossings, future acquisitions should focus on this X. Within the area owned by Hanson Aggregates.

Big-eared Woodrat

- The group was concerned that the habitat suitability map was too restrictive. They think of big-eared woodrat as a generalist species.
- If Scott Tremor (SDNHM) agreed with their assessment, they suggested trying to incorporate more data or different background points, which might improve the model output. Data sources mentioned include SanBIOS, data from Robert Fisher, surveys from Boulder Oaks preserve, the Salvation Army land, and the San Vicente Reservoir.
    - NOTE: Scott's opinion was that the woodrat model was a reasonable prediction of habitat suitability for *Neotoma macrotis*, in particular for the study area. The areas of concern identified by the group were largely steep slopes and south-facing aspects where woodrats are less likely to occur due to topography and lack of adequate vegetative cover. SanBIOS data were included in original modeling dataset. Our conversion of habitat suitability to resistance using a non-linear function will also address any overly conservative predictions of habitat suitability. A map of this resistance surface was uploaded to the Google Drive after the meeting.

California Mouse

- The group wasn't familiar with this species and didn't have any input on the products.

- NOTE: This species was included as an alternative to big-eared woodrat. It requires intact, mature shrublands, particularly chaparral, similar to the woodrat.

Comments from the herp group:

- Overall, the coarse scale of the models, data gaps, and input environmental variables used for modeling seem to limit the utility of these suitability models for connectivity analyses.
- For several species, the group was Interested in parameters used for model development (e.g. was urban included in models or complete excluded?)
  NOTE: Franklin et al. 2008 paper describing modeling methods for these surfaces have been uploaded to Google Drive.

Western Whiptail

- For western whiptail, the suitability map seemed adequate, but suitability gap near Mt. Woodson was of concern
- Recommendation: If connectivity for large animals encompasses pathways for small animals, include more considerations for small species in crossing designs to compensate – cost to do so will be limited.
- Question: Is the resistant kernel showing the core of connectivity area? Answer: Not necessarily, but for the herp surfaces, the coarseness of the scale and limited distribution and dispersal capabilities of some of the species made the corridors seem as though they were restricted to primary suitable habitat.

Western Toad

- Western Toad suitability seems to be much more limited than it should be – missing areas around Otay, near the coast, on Pendleton, and near suburban or urban areas
- Resistant kernel corridors for toad show restricted movement and around water bodies which seems counter-intuitive
- Omniscape corridors are concentrated in the upper NE corner of the map, which also seems odd – we believe this is driven by the degree and quality of habitat in the Ramona Grasslands drowning out the signal elsewhere.
- Factorial least cost paths aren't consistent with other corridor maps showing high flow in the NE corner of the map
  NOTE: This is because FLCP will force paths to go all across the landscape, creating paths where resistant kernel and ominscape may not be able to allow for flow.
- Suggestion to constrain analysis spatially: need small water bodies/drainages vs. large water bodies
- Overall, western toad may not be the best choice for movement analyses
  - Very localized, maybe just identify certain key areas where there's locally a high concentration
  - Should least cost path be focused on 67 rather than through whole core

Coachwhip

- Coachwhip had similar issues with datagaps and questions on adequacy of habitat suitability map
  - Concerns included that El Cajon was modeled as best for the species, suitable areas in the foothills, Wild Animal Park, and Rancho Guejito don't show up but probably should
  - In reality they move a lot and get wiped out of urban areas
  - If you could overlay spp data you might see it reflects sampling which might explain bias
    - Pitfalls not the best sampling method for snakes

    - Because this is based on topography we see suitable habitat in lowlands where 15+ major roads are

  NOTE: Examining the resistance surface may be helpful for this species
- Resistant kernel map doesn't make sense - There are not a lot of impediments for this species so this map seems too constrained
  NOTE: True constraints appear to be roads, urbanization and a western range edge
- Omniscape map shows occurrence at SR-67 and I-15 is a good place to cross which is hard to interpret

Comments from the large animal group:

- Interest in seeing comparison of movement paths (especially factorial least cost paths) for deer compared to bobcat compared to puma. Although there was some overlap, differences seem to reflect true differences in species behavior.
- Concerns about movement on east side of the study area and how to integrate roadkill data for Wildcat Canyon and to determine development plans on the Barona Reservation to take that into account in connectivity planning

Mule Deer

- Agreement that habitat suitability model for deer may underpredict in some important areas within the study area (e.g., Crestridge)
- Based on available data and biased sampling, correcting may be difficult
- Movement corridors did not seem to reflect the same issues though
- Factorial least cost paths across SR-67 seemed to be in locations that agreed with genetic data as well as prior monitoring of road crossings along SR-67
- Resistant kernel map for the species did not seem as helpful as omniscape for delineating corridors for the species.
- I-8 crossing a concern, especially given recent clearing of the existing underpass
- SR-52 movement seems overestimated as well

Puma

- No issues with movement probability identified
- Crossing locations from Factorial least cost paths seem appropriate given prior information about puma movement and roadkill locations
- Resistant kernel corridors in the south along San Diego River seem highly unlikely. Likely a modeling artifact and will be removed from corridor consideration
- Omniscape surface a bit harder to interpret as it's a little more broken up

Bobcat

- Also no issues with probability of movement surface
- Crossing locations from Factorial least cost paths seem appropriate given prior information about bobcat movement and roadkill locations
- Resistant kernel corridors show good north-south connectivity on either side of the highway, but limited movement across the highway
- Resistant kernels are coarse, but potential pathways seem feasible despite some likely overestimation of movement across I-8 and SR-52
- Omniscape surface less helpful. Does this mean bobcats can just move everywhere?
  NOTE: This analysis was likely affected by the fact that, from a movement ability perspective only, a bobcat (and same goes for puma) could disperse across the entire study area. We will adjust this

to run the analysis at the county-level to reduce edge effect and artifacts from modeling at this scale for large species.

Next Steps:

Prioritization

1. Implementation plan should include group's input
   Will be seeking stakeholder input again at a meeting in the first week of June
   We will also reach out to individual experts between now and then for input on specific items (e.g., Caltrans for road crossing feasibility, USFWS & CDFW for NCCP issues, etc.)

2. Multi-species validation – how to match up more species habitat with already mapped focal species
   For the following species, use models if they exist. If not, overlay points that we already have and line up with corridor maps and determine if we need specialized corridors:
   a. Ringtail
   b. Badger
   c. Arroyo Toad
   d. Cactus Wren
   e. Bats – might be similar to wrentit, so create structures that could be good for bats
   f. Stephens kangaroo rat
   g. California gnatcatcher
   h. Other T&E
   i. Quino checkerspot butterfly
   j. Hermes copper butterfly

3. Crossing structures
   a. Number of species served for each location – identify locations where multiple species may cross
   b. Location relative to roadkill hotspots
   c. Heat map of elevation adjacent to road to help with siting and design for species like wrentit and bats
   d. Distance to nearest structure (both proposed and existing – what's the frequency of crossing structures for a section of highway)
   e. Consideration of land ownership adjacent to proposed structure locations
   f. Structure design recommendation from published best management practices
   g. Provide short-term and long-term recommendations
   h. Have an action plan result from this study to include as many details as possible, e.g., length of fencing and costs

4. Linkage Prioritization
   a. Number of species served
   b. Edge to interior ratio
   c. Preserve state (core/noncore/etc.)
   d. Connectivity among veg types – is CSS connected to CSS at either end of linkages
   e. County land use data – SANDAG or others?
   f. Land use projections at parcel level: just in SD econometric model that incorporates planning – value of conserving land due to fire risk (Butsic et al. 2017)
   g. Undeveloped areas not currently conserved

Highway 67 Connectivity Meeting Notes
Corridor Management and Planning Stakeholders
Friday, May 12, 2017
10 AM – 12 PM

Attendees:

Cara Lacey, TNC
Kris Preston, SDMMP
Dave Mayer, CDFW
Michael Beck, EHL
Susan Wynn, USFWS
Kyle Rice, CDFW
Megan Jennings, SDSU
Kathy Zeller, SDSU (via phone)

Suggestions:

- Meet with or get information from Michael about Hanson's properties. They are very willing to coordinate efforts since they have more mitigation lands than their activities impact.
    - Follow up – Michael to talk with Hanson and get some maps/info that we can then overlay with our products to formulate a plan before they sit down with others
- There was a general desire to conduct a similar assessment at the county level. There was much discussion about what this would entail and what additional species might be included. Additional species recommendations included more grassland and desert species specifically: gnatcatcher, cactus wren, desert bighorn sheep, badger, jackrabbit, and possibly Stephens' kangaroo rat.
- The applicability of analysis / decision-making tools like this for other areas that don't yet have established MSCPs was also highlighted.
- For final stakeholder meeting and for report, it was suggested that results be put in context of the project goals and objectives of modeling regional movement. This point was brought up since there was some confusion about how to use the product for smaller, less vagile species.
- To this same point, it was suggested that we thoughtfully message information about the products we are providing. For example, in presenting the final corridor and corridor surfaces, two points of confusion ensued. One was the lack of connectivity for certain species in certain areas. It is important to highlight we are presenting an aggregate connectivity map and not a species-specific map and that this product was only focused on connectivity and not on core areas. Because of this, there was some concern that it could be misused and important areas could be discounted just because someone didn't see them on the map. Therefore, each product should have: 1) a reminder of what exactly the product is, and 2) what it could be used for, and possibly 3) what it shouldn't be used for.
- Also related to this was the suggestion to make the distinction in the results between species-specific conservation designs and reserve designs.
- Talk with Emily about getting final data sets on a password protected online GIS data base.
- Add the occurrence points for the T & E and other validation species to the final package.
- In the future, add the SDM probability surfaces from Kris once they're approved by USGS.
- Ask Van Butsic about including his developable parcel data in the study area in the final package
- The following points pertain to the scoring criteria:
    - Make it clear from beginning that each person develop a scoring criteria specific to their needs
    - Lay out, step by step, how to use the tool. For example, all things being equal – in a corridor, of a certain size, etc. how do you compare parcels.
    - What we present is just an example of how to go about scoring the parcels and it is not necessarily the right way to go about it given an application
    - Make parcel measurements (ha) more explicit in table
    - For habitat suitability points, anything under 0.5 should get a 1
    - For our example, show the parcels in the study area context

SR-67 Wildlife Crossing Structure Review Meeting Notes
Caltrans District 11 Office
Thursday, 18 May 2017
9:30 – 11:30 AM

Attendees:

Bruce April, Caltrans
Kim Smith, Caltrans
Carl Savage, Caltrans
Megan Jennings, SDSU
Kathy Zeller, SDSU

Started by discussing our strategy for identifying proposed crossing locations

- Used FLCP pathways and identified where they cross the road
- We looked for the densest clusters of points to reduce overall number of structures we would need to recommend
- We found clusters occurred within 300m zones, so we created 300m crossing zones to make recommendations
- When possible, within those zones, we selected sites where we could retrofit or improve existing structures

Major information sharing/messaging suggestions:

1. Add SR-67 postmile numbers (cross reference from shapefile) to crossing recommendation spreadsheet
2. Carl suggested plotting right-of-way on our structure maps – we can also add this info (width) to our spreadsheet
3. Managers we're working with most often use imperial units. I think we need to convert all our calculations for crossings and corridors to imperial units to make them easier to use and interpret
4. May want to highlight the mandate for this work
    a. State of CA has mandated Caltrans work with CDFW to address wildlife connectivity (AB 2087?)
    b. SR-67 identified by SDMMP, MSP, and EMP as a priority for wildlife connectivity
5. Carl suggested we also make very clear that our current recommendations are un-cost constrained
    a. A complete infrastructure plan would start with what we have produced and then we would need to work closely with Caltrans to refine them, then work up a cost estimate, then further refine based on available budget.
6. Suggested highlighting the maintenance that may be needed to deal with new proposed structures to give a clearer picture of the long-term commitment to the infrastructure

Organizational suggestions:
Kim requested prioritizing sites - we identified two ways we could do that

1. By low-hanging fruit – what improvements could easily and cheaply be made to improve existing structures? We have noted some of these in the spreadsheet and in the last SDSU report to Caltrans for the SR-67 median barrier safety project. What are the minimum maintenance actions that could be performed for improvement?
2. By highest priority for wildlife movement. Some areas are more important for wildlife movement or the configuration of a crossing lends itself to being more functional – we could prioritize using those metrics to highlight areas where cost might be higher but where there are fewer logistical issues with placement and the need is more justifiable

Carl mentioned biggest issues with changing structure types on an existing road are related to hydrology and engineering

- One issue with changing size of existing structures is changing sediment and water flow
    - Going smaller can mean clogs with sediment or upstream flooding
    - Larger can mean downstream sediment deposition

- Changes in structure material can also affect water flow
    - Faster through concrete, slower through corrugated steel pipe

In general need to review structure size recommendations for two aspects:

1. Grade separation – if we don't have enough to go as far below the road as the height of the new structure, the road must be raised. This means substantial additional costs
2. Right-of-way extent – increasing size of structures means they often need a wider footprint away from the road. In some sections a tight right-of-way won't allow for that

Additional considerations to think about in final structure recommendation review:

- Some of our longer width structures will need to be separated as they'll need supports. For example, a 12m wide structure would likely need to be 3 segments with 2 supports
- Discussed median barrier gaps that could be installed in the Lakeside grade section of SR-67 to reduce wildlife vehicle collisions. The barrier is entire for a car but there is a break and the two segments are offset to allow for a gap (~10'?) an animal could get through.
- Carl suggested that in areas where we may have hydrology or sediment issues, we could always consider pairing a wildlife crossing structure with a drainage structure. This could reduce some of the issues of having to meet all needs with a single structure that is less than ideal for either purpose.

Site-specific discussions

- Had general agreement that the Mt. Woodson crossing would be best as an overpass. Ownership may be a bit tricky but topography and rocky area makes further development in that area unlikely.
- SR-67 bridge over San Diego River is in private ownership by sand mining company and they're not interested on conservation, so our recommendations may not be helpful there in the near-term
- SR-52 crossing from landfill – this would not be new as I thought, but exists. Bruce said it's a triple pipe culvert and they are 5-6' tall. May just need some veg and maintenance. Connects mitigation land for the dump to Mission Trails
- I-8 structures may need site visits for more accurate recommendations, but existing structure at Flinn Springs may be usable. Major design reconfiguration will be necessary at I-8, Alpine Blvd, Peutz Valley Road crossing

To address fencing that crosses driveways on SR-76 (similar to issues on SR-67), they installed returns that loop around and send the animal back in the other direction. We could use those or include them as a BMP to avoid putting animals in driveways or on the road at driveways. No good evidence for how well those work.

Also installed big boulders at the entrance to large box culverts to allow water flow but deter OHV access where it was likely to be an issue. Could add this as a BMP

Discussed jump-outs. We should add these, as appropriate to SR-67 design. May need to establish final fencing locations to determine where jump outs would be appropriate. Add it as a BMP with locations TBD.

We may be able to look at the costs of SR-76 as an example. Caltrans had a bottom line for costs, but EMP helped fund the delta over and above that to ensure adequate wildlife crossing structures were a part of the new construction.

Highway 67 Connectivity Meeting Agenda
Corridor and Crossing Structure Product Review
2 June 2017
1:00 PM – 4:00 PM
USGS Conference Room
4165 Spruance Rd, San Diego, CA 92101
Contact: Megan Jennings / 760.214.2145 (mobile) / mjennings@mail.sdsu.edu

Objective: To review completed data products for the SR-67 Connectivity Planning Project and solicit stakeholder input. These products include completed corridor maps and associated decision guide as well as crossing structure placement and infrastructure recommendations for SR-67 and other major roadways within our study area.

1. Welcome and introductions

2. Review purpose, overview, and objectives

3. Presentation on data analysis and map products to be reviewed

    - Corridor maps and data attributes
    - Prioritization and decision support tool
    - Review period for corridor products

    BREAK

    - Crossing structure placement
    - Infrastructure recommendations
    - Review period for crossing structure recommendations

4. Question and feedback session

5. Review of final project data delivery

Highway 67 Connectivity Meeting Notes
Corridor and Crossing Structure Product Review
2 June 2017
1:00 PM – 4:00 PM

Meeting Conveners: Megan Jennings, Kathy Zeller, and Rebecca Lewison

Attendees:
Kris Preston, SDMMP
Cheryl Brehme, USGS
Carlton Rochester, USGS
Amy Vandergast, USGS
Amber Pairis, CDFW
Udara Abeysekera, CDFW
Simona Altman, CDFW
Sally Brown, USFWS
David Mayer, CDFW
Trish Smith, TNC
Robert Fisher, USGS
Michael Beck, EHL
Mary Niez, County of SD – DPR
Hans Sin, CDFW
Carol Williams, CDFW
Kyle Rice, CDFW
Gail Sevrens, CDFW
Susan Wynn, USFWS (call-in)

Corridors

Input from stakeholders:

- Scoring / decision support tool could be used not only for parcel acquisitions, but also for management decisions around connectivity in areas you already own/manage.
- Make sure to mention that spatial context is really important when using the data to make parcel and management decisions. Encourage end-users to not only use corridor attributes, but also think about the location in the greater study area context. For example, if your area of interest is in one of the only corridors linking large lands from east to west, this might carry more weight than if your area of interest is in the middle of a large natural area with ample connections.
- Stakeholders discussed gathering a working group to discuss and vet a scoring rubric that could vetted and used among management agencies to meet common connectivity objectives.
- Stakeholders stressed that careful application of the tool will be important and that it should NOT be used in a 'plug and chug' fashion since there are many factors to take into consideration.
- Highlight that the outer 20-30% of corridor values is not 'bad' and that in fact, that might be the area where it is most important to conserve since these areas contain some of the last N-S and E-W linkages across the study area.
- Stakeholders emphasized that as changes occur with land ownership and development, that this tool may have to be updated over time.
- There was a little confusion about why some of the highest connectivity values ran across SR-67, Scripps-Poway Parkway, etc. We should highlight in the report that this does NOT mean that these areas are good for connectivity or that they aren't a barrier to movement, but instead that the results emphasize the need for land acquisition and crossings in these areas to ensure continued flow.
- It was also recommended to emphasize the limitations of this product. It is NOT intended as a catch-all for all species / movers in the study area but is specific to the 6 target species we used and the land facet corridor that was added. Again, it is also NOT to be used to examine connectivity for single-species, but instead for multi-species connectivity. Stakeholders also had to be reminded that this was a connectivity-only product and it was not to be used to identify core areas or areas of good breeding habitat.
- There was much discussion of the need for a similar analysis to be conducted over the entire county. For this to occur, more species would need to be added (i.e. a grassland species, desert species, aquatic species, etc.). Funding would need to be secured.
- The County wished to look at the product in relation to their master trails plan.

- The stakeholders were interested in the Van Butsic developable parcel layer and wanted it to be added to the list of deliverables. There was some concern over errors in land ownership of this layer, so Kris volunteered to overlay it with the most recent protected areas layer and clip out those parcels.

Road Crossings

Input from stakeholders:

- Include 'scuppers' in BMPs to allow for the safe passage of small animals across a road.
- There was concern about the inclusion of rip rap on the underpasses. Animals are hesitant to cross rip rap, but if it is not there, erosion and a perched culvert is more likely.
- This led to a discussion of dual siting of crossings so that, for example, one underpass would be for hydrological requirements and the other would be for wildlife.
- It was also suggested that if pipe culverts were to be used, that they not be coated with zinc since this has been shown to be toxic to wildlife (maybe add to BMPs).
- There was a suggestion to add to the crossing recommendations table what the current crossing structure looks like if there is one (height, width, etc.). This can be done for SR-67 but not for other roadways at this point.
- It was suggested that we try to limit the length of any overpass. The cost of overpasses increased with length and maintenance costs are high. The cost of wildlife structures is often a hard sell with the public so it might be good to project out how many years it would pay for itself by reduction of WVC.
- Again, we need to make sure we emphasize that our crossing structure recommendations are not cost constrained and that they need to go through multiple reviews with Caltrans engineers, planners, etc., before the final recommendations / costs are developed.

Requested Deliverables

- Report
- Raw connectivity flow value
- Normalized flow surface
- Resilience and connectivity surface
- Habitat suitability models for each of our 6 target species across SD county
- Corridors
- Corridor Isopleths
- Developable parcels
- Corridor metadata
- Decision support flowchart
- Example scoring rules with 2 example parcels
- Road crossing zones and structure locations
- Road crossing recommendations
- All GIS data provided as a Layer Package so they display as in report
- PDFs of Stakeholder meeting presentations along with meeting notes
- We can provide resistance surfaces and corridors for individual species upon request.

APPENDIX G: WILDLIFE CROSSING STRUCTURE LITERATURE REVIEW REFERENCES

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