COMPREHENSIVE MULTI-SPECIES CONNECTIVITY ASSESSMENT AND PLANNING FOR THE HIGHWAY 67 REGION OF SAN DIEGO COUNTY, CALIFORNIA

SAN DIEGO STATE UNIVERSITY

Final Report
June 2017

Prepared for

SANDAG No. 5004388
Task Order 3

Prepared by

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List of Acronyms and Abbreviations

AWDT – Average Weekday Daily Traffic

BISON – Biodiversity Information Serving Our Nation

Caltrans – California Department of Transportation

CDFW – California Department of Fish and Wildlife

CEHC – California Essential Habitats Connectivity Plan

CFWO – Carlsbad Fish and Wildlife Office

CMSP – Connectivity Management Strategic Plan

CNLM – Center for Natural Lands Management

EHL – Endangered Habitats League

FLCP – Factorial Least Cost Path

GBIF – Global Biodiversity Information Facility

IEMM – Institute for Ecological Monitoring and Management

MCB – Marine Corps Base

MHCP – Multiple Habitats Conservation Plan

MOM – Master Occurrence Matrix Database

MSCP – Multiple Species Conservation Plan

MSPA – Management Strategic Plan Area

MSP – Management Strategic Plan

NCCP – Natural Community Conservation Plan

SANDAG – San Diego Association of Governments

SDMMP – San Diego Management and Monitoring Program

SDSU – San Diego State University

SR – State Route

TNC – The Nature Conservancy

USFWS – United States Fish and Wildlife Service

ACKNOWLEDGMENTS

We are grateful to a number of people for their contributions that made this research possible. First and foremost, the data holders and experts who willingly shared data and provided input and advice: Winston Vickers and Walter Boyce (University of California, Davis); Holly Ernest (University of Wyoming); Amy Vandergast and Anna Mitelberg (U.S. Geological Survey); Scott Tremor (San Diego Natural History Museum); Mike Tucker (Marine Corps Base Camp Pendleton); Markus Spiegelberg (Center for Natural Lands Management); Robert Fisher (U.S. Geological Survey); Cheryl Brehme (U.S. Geological Survey); Kris Preston (USGS, San Diego Management and Monitoring Program); Randy Botta (California Department of Fish and Wildlife); and Drew Stokes (San Diego Natural History Museum). During the data analysis and processing phase of this project, we received assistance from a number of other researchers who shared code and data sources. Becca Lewison provided guidance, advice, and project management support from the initial stages of project development to completion. We are thankful to Van Butsic for sharing parcel-level development projections for our study area, Brad McRae for sharing the OmniScape code and providing assistance to guide us in its use, Jeff Jenness and Brian Brost for assistance in troubleshooting the land facet corridor analysis, Jenn Weaver for guidance and advice on our approaches for species distribution modeling, and Kevin McGarigal and Javan Bauder who also provided input on species distribution model development. During the development of the products for our end-users, including the decision support tool and wildlife crossing infrastructure recommendations, we had input and assistance from a number of people. We appreciate Shasta Gaughen for providing guidance on incorporating cultural values into our corridor attribution and Jaime Lennox from the Southern California Information Center for conducting the search of archaeological records, Megan Gonzales and Sierra Suttles for their work on conducting the comprehensive literature review, and Kelly Lion for providing additional references on wildlife crossing structure recommendations. The input from our stakeholders was also invaluable. We appreciate their attention and suggestions they provided that improved the quality of our approach and final data products. In particular, Amber Pairis and Udara Abeysekera played an important role in providing support during meetings and highlighting project activities. We are also grateful for the additional time that Kris Preston, Susan Wynn, Michael Beck, Dave Mayer, Kim Smith, Bruce April, and Carl Savage gave to helping us hone our recommendations and deliverables. Finally, we would like to thank Kris Preston for support throughout the project.

EXECUTIVE SUMMARY

Through a comprehensive, multi-species connectivity analysis using robust analytical approaches, we created a connectivity plan, tools to facilitate the implementation of this plan, and a wildlife crossing infrastructure plan for key roadways in our study area. Through this data-driven approach, we:

- Assembled a multi-species connectivity analysis using a suite of data types and species complemented by a landscape-focused land facet analysis
- Analyzed a suite of data types using cutting-edge analytical techniques appropriate to each data type
- Leveraged survey and monitoring data from our study region, producing a data-informed connectivity plan without the collection of any new field data
- Identified and mapped 12 spatially-explicit focal species corridor segments and one land facet corridor to facilitate wildlife movement within the SR-67 region of San Diego's Multiple Species Conservation Plan area
- Assessed the potential functionality of those corridors for additional species including five federally listed species and 13 other species of interest
- Attributed those spatially-explicit corridors with data on land conservation status, biological variables, and threats and stressors to inform decision-making
- Created a decision support tool for scoring potential acquisitions, habitat restoration projects, or other land management and planning decisions
- Used our connectivity models, species data, site specific information, and previously collected data on crossing use and roadkill to inform wildlife crossing infrastructure recommendations for SR-67 as well as other roadways within our analysis area
- Worked with a variety of stakeholders throughout this process to gather information, feedback, and key input to generate a connectivity plan and conservation tool that could readily be implemented by the diverse range of land management and planning entities working in this region of San Diego County

INTRODUCTION

Importance of Connectivity

Habitat fragmentation and degradation are two of the greatest threats to habitat availability and quality, posing a direct risk to species' persistence and consequently, to biodiversity. As anthropogenic features such as roads and housing developments alter the landscape, landscape connectivity for wildlife may be reduced. Current land management plans throughout North America and Europe are designed to protect biodiversity by establishing a network of core habitat areas that are connected via corridors or linkages. The central tenet of this large-scale conservation planning is that viable populations and natural communities can be supported by a connected landscape network (Beier *et al.* 2006, Crooks and Sanjayan 2006, Boitani *et al.* 2007, Barrows *et al.* 2011), particularly as the landscape becomes altered by anthropogenic features. Landscape connectivity allows for movement among patches of suitable habitat, reduces the chance of extinction and the effects of environmental variability on small populations (Brown and Kodric-Brown 1977), and maintains gene flow between populations in patchy landscapes (Noss 1987). Connectivity also allows for more rapid recovery of populations after events such as fire and disease outbreaks. Over longer time scales, and in the face of changing abiotic conditions, connectivity may also prove critical for range shifts in response to landscape changes caused by a changing climate and altered disturbance regimes (Hannah *et al.* 2002, Heller and Zavaleta 2009).

Roadways in particular pose a significant challenge to landscape functioning (Laurence and Balmford 2013). Though roads can have many negative indirect effects on wildlife, two mechanisms directly impact habitat suitability and continuity (Fahrig and Rytwinski 2009): the *barrier effect* whereby the road blocks species' movement across the landscape, and *direct mortality* through wildlife-vehicle collisions (Bissonette 2002). The degree of impact of a road may depend on several factors such as the location of the road relative to open space and protected habitats, traffic volume and traffic speed (Fahrig *et al.* 1995), and the sensitivity of species affected by the road. Although many conservation network plans acknowledge the negative effects roads can have on connectivity, few have thoroughly assessed and developed approaches to mitigate barrier and mortality effects of roads that fall within ecological networks.

San Diego County Preserve Network and State Route 67

In southern California, the landscape-scale network approach has been adopted in response to the widespread habitat conversion and fragmentation that has resulted from development in the region (Riverside County 2003, County of San Diego 1998). Specifically, in San Diego County, there are a number of public and private conservations plans and ecological networks, including the San Diego Multiple Species Conservation Program (MSCP) and Multiple Habitats Conservation Program (MHCP), that were designed to create an interconnected preserve system. The overarching goal of these plans is to preserve the biological diversity of San Diego County through the conservation and management of functional habitats and linkages[1,2,3]. In January

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[1] Management Goals and Objectives (Section 1.51, p.49-50) under the Framework Management section of the San Diego MSCP Plan identify viability of ecosystem function and processes, long-term persistence of populations, functional habitats and linkages, as well as ability to adapt to changing circumstances as key goals of the plan.
[2] Poway Sub-Area Plan (SAP) p. 2-10 identifies two regional wildlife corridors through Poway and into adjoining jurisdictions, one of which is bisected by SR-67 study area.

2011, the Connectivity Monitoring Strategic Plan (CMSP) for the San Diego Preserve System was drafted. One of the primary objectives for connectivity management identified in the CMSP was to "inform adaptive management and other conservation actions by identifying important movement areas/chokepoints between cores for various species."[4] Based on the findings from previous research, as well as the initial studies conducted to meet the Priority Objectives in the CMSP, State Route (SR)-67 was named as one of the primary barriers to wildlife movement and connectivity in the MSCP and MHCP areas. The identification of SR-67 as a major threat/stressor was reiterated in the 2013 Management Strategic Plan (MSP)[5] for the MSCP area, which prioritized further connectivity research in the vicinity of SR-67 and the development of a wildlife crossing infrastructure plan as a management and mitigation goal[6]. This area has also been characterized as a priority area by the California Essential Habitat Connectivity Project (CEHC, Spencer *et al.* 2010) where local-scale analyses and road crossing improvement plans were recommended prior to the development of site-specific connectivity management and enhancement goals.

Further discussions about subregional connectivity in the area were prompted by a California Department of Transportation (Caltrans) proposal for a median barrier safety project as the major widening and highway improvement project that is expected to occur within the next 20 to 30 years. These projects may further challenge wildlife movement, but they also provide opportunities to make significant improvements to wildlife connectivity. Although the widening of SR-67 may not be initiated until 2040, a comprehensive, data-driven assessment is necessary to facilitate conservation planning in the interim. This planning will ensure acquisitions, habitat restoration, and management actions to establish a functionally connected landscape can progress towards a strategy that will support viable wildlife populations in perpetuity.

Multi-species Connectivity Planning for SR-67

In response to this need for data on wildlife movement along SR-67, The Institute for Ecological Monitoring and Management at San Diego State University (SDSU) has conducted a multi-faceted research project to examine connectivity across SR-67 and to preserve or improve existing crossings through identifying functioning crossing features along the highway. This assessment leverages previously collected telemetry, occurrence, camera, and road-kill data to conduct a multi-species comprehensive connectivity assessment for the SR-67 region. The goal of this project was to provide a data-driven analysis that would inform connectivity planning for the area. Our ultimate objective with this research was to improve functional connectivity of the SR-67 area and increase permeability of the roadway through installation of larger and appropriately-sited crossing structures. The analysis and data products produced during this project are intended to promote proactive conservation efforts within an area of the MSCP that has frequently been cited as a major threat to wildlife movement. One of the main objectives was to develop recommendations for improving connectivity across SR-67 and to preserve habitat and wildlife corridors adjacent to SR-67 prior to the initiation of any road development or improvement. This synthesis of data will facilitate the management of healthy wildlife

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[3] Poway SAP p. 3-2 highlights the needs to maintain functional connectivity within Poway as well as between Poway and adjoining jurisdictions.
[4] CMSP, p.5
[5] MSP, Volume 1, p. 2-2
[6] MSP, Volume 2, p. 4-31

populations within the MSPA by providing data-driven recommendations that can be used to take immediate action to improve landscape connectivity in the SR-67 area, and can serve as a template in other regions of San Diego's NCCP plans faced with limited connectivity caused by roadways.

Connectivity is often considered from two different perspectives, physical and functional connectivity. *Physical connectivity* indicates whether there is structure connecting two patches of habitat, whereas *functional connectivity* accounts for how wildlife respond to that structure and the implications of those considerations for the species of concern (Taylor *et al.* 1993, Tischendorf and Fahrig 2000a, 2000b). The distinction between physical connectivity and functional connectivity in fragmented landscapes is critical when implementing conservation and mitigation measures to prevent irreversible habitat fragmentation. There are a variety of factors that can affect this response, including but not limited to, life history traits of the affected species, habitat configuration, degree of habitat fragmentation, and type of fragmenting features (*e.g.*, roads, houses). Furthermore, this response will differ among species with some demonstrating a greater sensitivity to these factors than others. Quantifying or assessing landscape connectivity, however, is non-trivial (Fagan and Calabrese 2006) given the context-dependent nature of connectivity (Crooks and Sanjayan 2006) and the expense and effort of acquiring movement data for species of interest. Currently, one of the primary barriers to conducting data-driven connectivity analyses is the general lack of knowledge of how animals are currently using the landscape, and how landscape use changes in response to dynamic landscape processes over time. For this reason, one of the other main objectives of this research was to identify approaches for data synthesis that would allow us to leverage the existing data that had been collected during monitoring and management activities in San Diego's preserve network. We investigated a range of analytical techniques that would support a robust, comprehensive, data-driven study using cutting-edge methodologies to assess and map connectivity that were appropriate for the species-specific types of data that were available.

To fully assess connectivity throughout the portion of the preserve network surrounding SR-67 and provide clear, implementable actions to achieve the desired status of landscape connectivity, we carried out a two-phased project. Phase I focused on the collection, organization, and analysis of available data for a suite of focal species as well as comprehensive mapping of corridors. In Phase II, we utilized the data and resulting maps generated in Phase I to develop spatially-explicit corridors attributed with relevant management data that was linked to the Management Strategic Plan for the preserve network (Figure 1) as well as a wildlife infrastructure improvement plan for improving permeability of SR-67 and other roadways in the study area. This detailed infrastructure plan for the roadway identifies recommendations for improvements that can be made prior to the anticipated widening as well as the major wildlife infrastructure repairs and replacement that would take place during widening. Phase II products were developed in cooperation with land managers, conservation planners, Caltrans, and other stakeholders in the region.

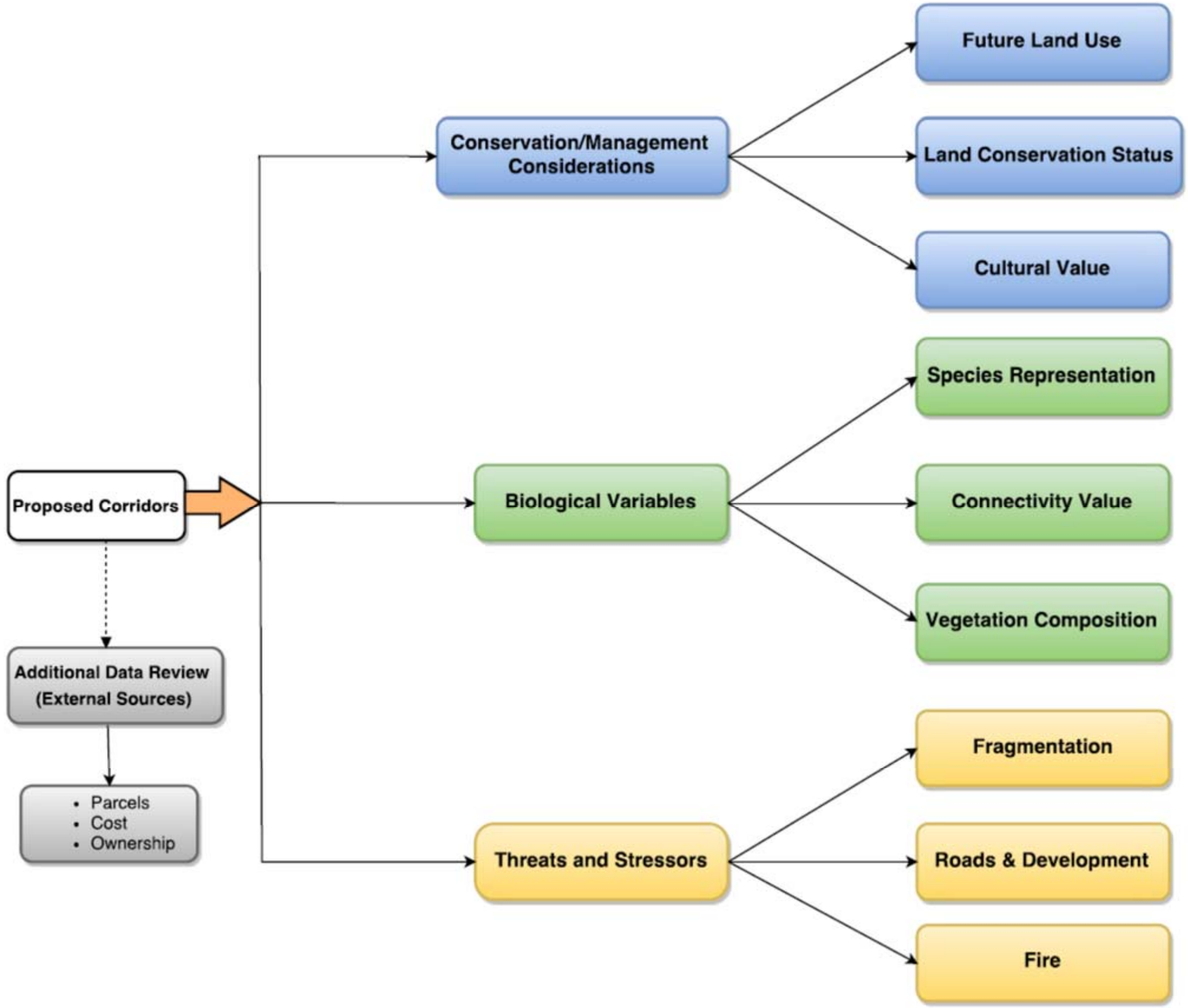

Figure 1. The corridor attribution guide developed for this project illustrates the three main categories of attributes as well as example data types for each.

The data integration, compilation, and analysis were used to inform the development of specific data products for this project:

Phase I – Data synthesis, analysis, and corridor mapping
- Habitat suitability surfaces for all focal species
- Probability of movement and landscape genetic surfaces for selected focal species
- Resistance surfaces for all focal species
- Connectivity flow for all focal species

Phase II – Identification and prioritization of management actions
- Spatially-explicit corridors and corridor attributes
- Decision support guide for using corridor criteria in decision making
- Infrastructure placement and design for wildlife road crossings

Stakeholder Coordination

A key component to the development of the geospatial and data products we produced for this project was stakeholder engagement. Since the inception of this project, we have coordinated with stakeholders to ensure we had as much information as possible on prior and current research that could inform our assessment. Based on this input, we have worked to identify any opportunities to leverage existing data and efforts of other projects. We also worked to share our findings during the course of this project with other researchers, planners, and land managers to facilitate wildlife and connectivity management in this region of San Diego County. 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.

The process of stakeholder engagement began before this project started, in September 2014. That initial meeting, which served as a platform for information-sharing and coordination of research and planning activities involving SR-67, allowed us to fully form the research proposal for this project. 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 F1). 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. Details on each of the engagement sessions as well as agendas, notes, and attendee lists from these meetings are included in Appendix F.

Through this engagement process, we have been able to hone and refine our analyses and data products in ways that will best serve the end users of our products. The requests and suggestions we received during our feedback sessions not only improved our data products and recommendations, but also have allowed our stakeholders to envision using these data products and influence their design and delivery.

METHODS

Study Area

The study was conducted within the San Diego Multiple Species Conservation Plan Area and a portion of the Draft North County Multiple Species Conservation Plan Area in southern California. This project was focused on areas surrounding SR-67 in central San Diego County between Mapleview Rd. in Lakeside and Etcheverry Street in Ramona, CA. The natural habitats and protected open space in the area are primarily publicly owned, and include Sycamore Canyon and Goodan Ranch Preserves, Boulder Oaks Preserve, San Vicente Highlands Preserve, Iron Mountain, Ramona Grasslands Preserve, San Dieguito River Park lands, and a portion of the Cleveland National Forest in the eastern portion of the study area. The analysis area included ~54,000 hectares (~133,500 acres) within the region identified as Management Unit 4 in the MSP area. Beyond the roadway, we evaluated connectivity based on previous data collected in MSCP core preserves 5, 6, 12, and 13 (Figure 2).

Elevation across the study site ranged from 58 meters (m) in the western section of the San Diego River and 1,110 m at the highest point of the study area, El Cajon Mountain. Vegetation types in the study area varied with elevation and proximity to the roadway. Habitat types in the study area varied with both elevation and distance from the coast, but was predominantly a shrubland ecosystem. Habitats across these areas included coastal sage scrub dominated by California sagebrush (*Artemesia californica*), chaparral habitat types generally dominated by scrub oak (*Quercus berberidifolia*), ceanothus (*Ceanothus* sp.), or chamise (*Adenostoma fasciculatum*), oak woodland with coast live oak (*Quercus agrifolia*), grasslands dominated by non-native annual grasses, riparian zones with an oak *(Quercus agrifolia*) or sycamore (*Platanus racemosa*) overstory and herbaceous understory, as well as urban and altered areas. Sections of the study area within the highway right-of-way and near industrial and urbanized areas near both Ramona and Lakeside were dominated by a mix of non-native plants (*e.g.*, *Bromus* spp., *Avena*, spp., *Centaurea melitensis*, and *Ricinus communis*), and barren or sparse areas, interspersed with coastal sage scrub and chaparral. The Mediterranean-climate of the study region is characterized by hot, dry summers and mild, wet winters with precipitation often less than 300 millimeters (mm).

State Route 67 is a highway that runs north and south for a distance of 24.38 miles from its southern terminus at Interstate 8 in El Cajon, CA to its northern end at the intersection of SR-78 in Ramona, CA. The highway is a four-lane divided freeway from El Cajon to Lakeside, CA, where it becomes an undivided highway ranging from two to four lanes. In 2008, traffic volumes on this section of highway ranged from 23,400 Average Weekday Daily Traffic (AWDT) to 26,600 AWDT. Expanding development in the backcountry of San Diego County has led to increasing traffic volumes on the road, which has in turn, added to traffic congestion. In addition, the speed at which vehicles are traveling on the highway has increased over the last decade, resulting in a number of severe and/or fatal collisions creating concerns for human. The convergence of a heavily traveled roadway bisecting the natural habitats along SR-67 has also led to a concurrent concern about safe road crossings for wildlife and wildlife-vehicle collisions, which we examined in this assessment.

Data Synthesis

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. San Diego County was the study area extent used to develop species habitat use, movement, and landscape genetic models. The connectivity and road crossing analyses were conducted in the SR-67 study area, described above and included a buffer to account for possible edge effects produced by the models (Figure 2). We used corridor attributes as the basis for a conservation decision-support tool and the road crossing attributes to prioritize crossing locations and provide wildlife-specific recommendations for the wildlife infrastructure plan. Methodological approaches are summarized below and detailed methods are provided in Appendix B.

Focal Species and Environmental Variables

Through stakeholder input and discussions with local biologists, we identified a number of focal species for this analysis. This initial list was narrowed to nine species that had adequate data for analysis and represented a wide range of movement abilities and habitat requirements. Species and data sources are listed in Table 1.

We used environmental variables thought to affect habitat use and movement for the focal species. These included topographic, land cover, water, and human development variables (Table 2). These environmental variables were used for all species except for puma. The puma models were mostly developed during previous research 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.

Before running the models, we smoothed each environmental variable using various smoothing factors to capture the appropriate scale, or zone of influence for each variable for each species. We ran all our models for each variable at each scale and selected the scale for each variable that resulted in the best model performance for each species.

Habitat use and resistance modeling

For species with occurrence points, we combined occurrence points with the environmental variables to develop ensemble Species Distribution Models (SDMs, Araujo and New 2007, Grenouillet *et al.* 2011). These SDMs were used to predict habitat suitability across San Diego County. We assumed areas with a high habitat suitability would have a low resistance to movement and areas with a low habitat suitability would have a high resistance to movement. Therefore we used a non-linear inverse transformation to convert habitat suitability to resistance for each species.

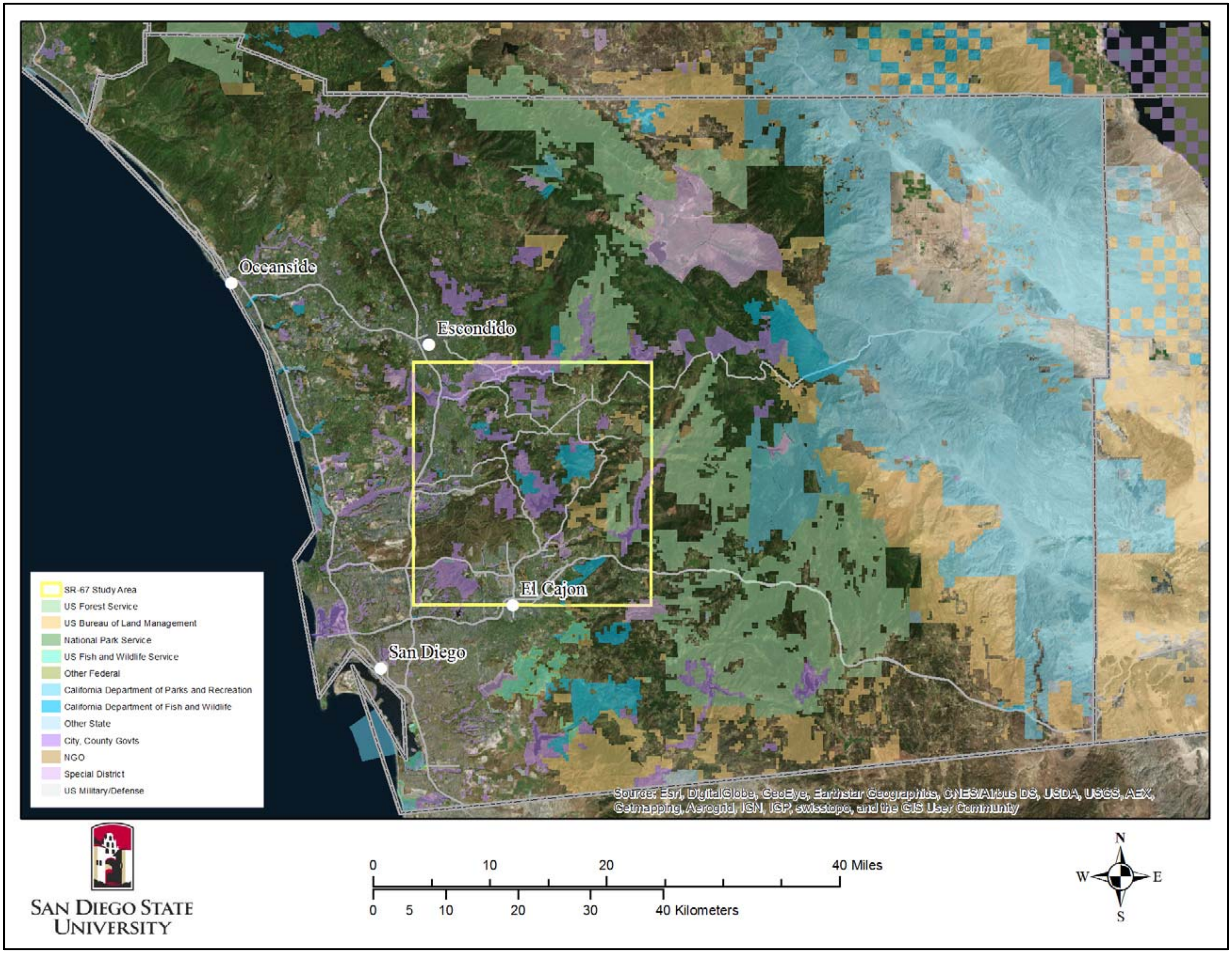

Figure 2. Map of SR-67 study area, depicted in yellow box within the context of San Diego County's network of conserved lands.

Table 1. Focal species, available data types, data sources, and analytical models used in the analysis. Data sources 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; 8) Mitelberg and Vandergast 2016; 9) Ernest *et al.* 2014 and Zeller *et al.* 2016; 10) Franklin *et al.* 2009.

Focal species ***(scientific name)***	**Data type(s)**	**Data source(s)**	**Analytical method(s)**
California mouse *(Peromyscus californicus)*	Occurrence points	SDNHM Mammal Atlas[1], SanBIOS[2]	Species Distribution Model
Big-eared woodrat *(Neotoma macrotis)*	Occurrence points	SDNHM Mammal Atlas[1], SanBIOS[2]	Species Distribution Model
Wrentit *(Chamaea fasciata)*	Occurrence points	eBIRD[3]	Species Distribution Model
Mule deer *(Odocoileus hemionus californicus)*	Occurrence points & Genetic data	SDNHM Mammal Atlas[1], SanBIOS[2], SDSU[4], MCB Camp Pendleton[5], CNLM[6], SDMMP MOM[7], USGS[8]	Species Distribution Model & Landscape genetics analysis
Bobcat *(Lynx rufus)*	GPS telemetry & genetic data	SDSU[4]	Resource and Movement Selection Functions & Landscape genetics analysis
Puma *(Puma concolor)*	GPS telemetry & genetic data	University of California, Davis[9]	Resource and Movement Selection Functions & Landscape genetics analysis
Coachwhip *(Coluber flagellum)*	Species Distribution Model	USGS[10]	Species Distribution Model
Western whiptail *(Aspidoscelis tigris)*	Species Distribution Model	USGS[10]	Species Distribution Model
Western toad *(Anaxyrus boreas)*	Species Distribution Model	USGS[10]	Species Distribution Model

For species with GPS telemetry data (puma and bobcat) we performed two analyses. First, we estimated resource use using a point selection function, which we used for estimating the relative probability of habitat use across San Diego County. Second, we estimated resource use during movement events with a path selection function (PathSF, Cushman *et al.* 2010, Zeller *et al.* 2016), which we used to estimate the relative probability of movement across San Diego County. We used the inverse of the probability of movement surfaces to estimate resistance for puma and bobcat.

For species with genetic data (puma, bobcat, and mule deer), we performed a landscape genetic analysis, which correlates the genetic distance between individuals across the landscape with the resistance distance between individuals across the landscape (Manel *et al.* 2013). This analysis estimates resistance directly so no transformation to resistance was needed. To develop the final resistance surface for species with genetic data, we multiplied the resistance surface derived from the SDM or PathSF analyses with that derived from the landscape genetic analysis and rescaled this surface from 1 – 100 (1 = low resistance and 100 = high resistance; Zeller *et al.* 2017).

Table 2. Environmental variables used in developing habitat use and resistance surfaces for each focal species.

	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 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

A depiction of the data types and analytical methods used to estimate resistance for each species is provided in Figure 3.

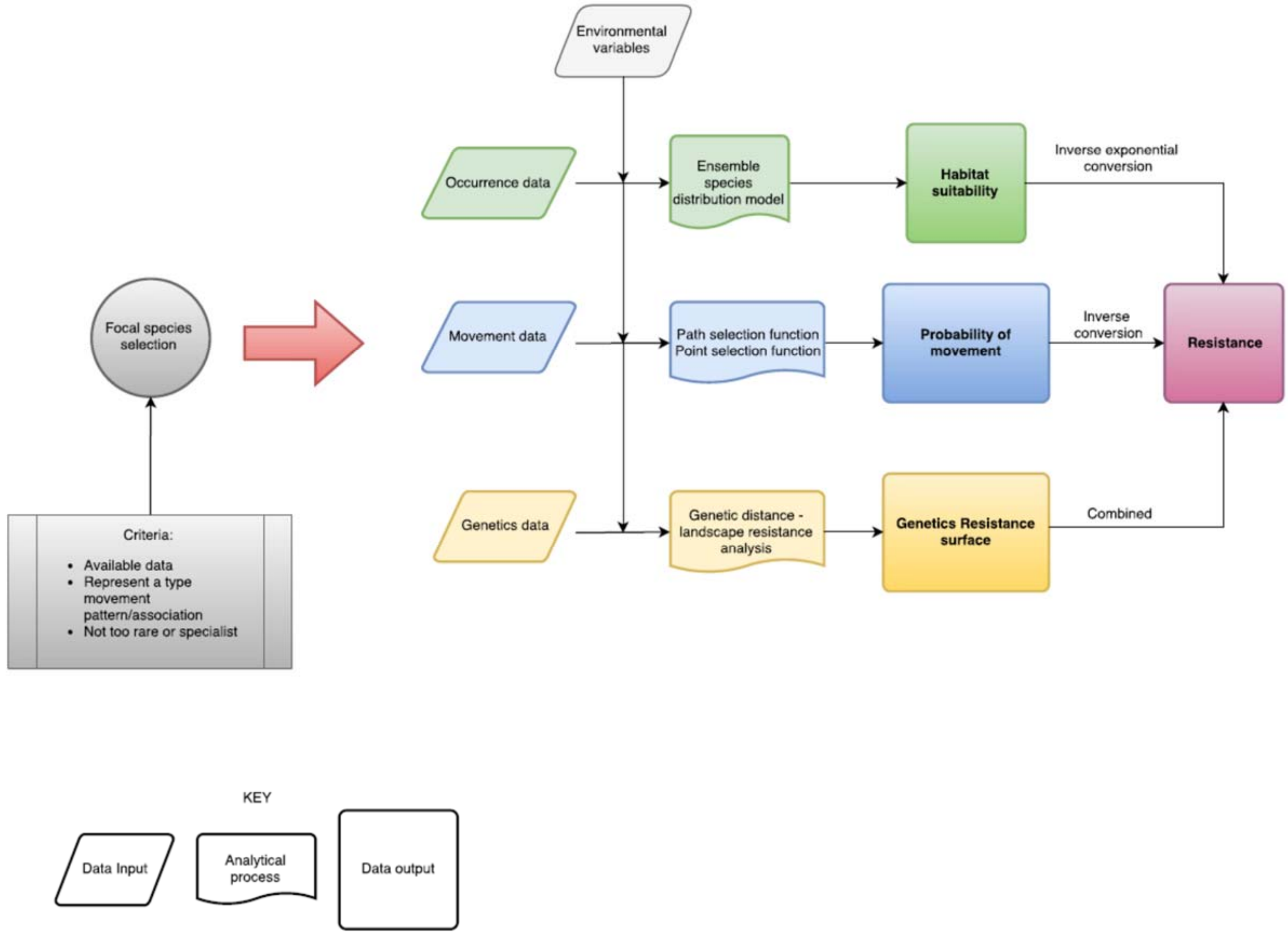

Figure 3. Analytical approaches used to develop resistance from each of the data types we had available for the multi-species connectivity planning project

We assessed the SDMs for coachwhip, western whiptail, and western toad that had been developed by Franklin *et al.* (2008) and provided by USGS. These SDMs were developed at a regional scale and at a coarse spatial resolution. Because of this, the predictive ability of these models was poor in the SR-67 study area. The input we obtained from the stakeholders confirmed that these layers were inadequate for connectivity modeling for this project. Therefore, we decided not to use these data or these species in the connectivity analysis. We did, however, use these data in the corridor attribution process.

Connectivity Modeling and Identification of Multi-species Corridors and Road Crossing Locations

Across the final resistance surface developed for each species, we identified landscape corridors using two connectivity modeling approaches; Resistant kernels (Compton *et al.* 2007) and OmniScape (McRae *et al.* 2016). Resistant kernels require the identification of source points in the study area from which connectivity is modeled. We identified 1,000 source points for each species. These points were distributed probabilistically on each habitat suitability surface so that areas with higher habitat suitability had more source points than areas with lower habitat suitability. OmniScape sources were identified as any pixel that had a resistance less than 20. To create a multi-species connectivity model, we averaged the connectivity surfaces derived from the resistant kernel analysis across all species. Discrete corridors were identified on this multi-species connectivity surface by clipping this surface to the top 30% of connectivity values (70-100% of connectivity values). These corridors were expanded slightly by including areas identified from the OmniScape analysis that enforced east-west and north-south connectivity across the study area. We divided the final corridor into 12 different sub-corridors based upon the location of protected areas and other important features on the landscape.

From this connectivity surface we also produced three additional layers that may be helpful in land management and planning; corridor isopleths, a normalized flow surface, and a corridor resiliency map. The corridor isopleths depict the top 10% of the multi-species connectivity surface (areas with the highest average connectivity across all six focal species), the top 10-20% of the connectivity surface, and the top 20-30% of the connectivity surface. The normalized flow surface shows the connectivity surface in terms of how concentrated or diffuse connectivity is across the study area. Areas of concentrated flow indicate naturally restricted flow, such as steep canyons, restricted flow due to human development, or a combination of these factors. Where flow is concentrated due to human development might be areas facing more imminent fragmentation threats. Normalized flow was derived by running the resistant kernel connectivity model across a uniform resistance surface (where there is no restriction of movement), and then dividing the multi-species connectivity surface by this unrestricted connectivity surface. The corridor resiliency map used a layer developed by The Nature Conservancy that depicts resiliency of areas to climate change. We multiplied this map by the multi-species connectivity surface to derive a map where high values indicate areas that are both good for connectivity and resilient to climate change.

We also conducted a Land Facet corridor analysis (Appendix E). Land Facets identify areas of similar topographic and climactic makeup. Corridors based on these land facets have been promoted as a way to ‘preserve nature’s stage’ in the face of climate change and allow for flow amongst similar topographic and climatic features (Anderson and Ferree 2010, Beier and Brost

2010). We identified 15 land facets across the study area, created resistance surfaces for each land facet, and derived corridors for each land facet using a least cost corridor analysis. Our multi-species corridor generally overlapped these land facet corridors, with the exception of one land facet composed of gentle slopes at mid-elevation with high solar insulation. This land facet encompassed grassland features across the study area, specifically, the Ramona grasslands. Because none of our focal species were associated with grasslands, we added this single land facet corridor to our final corridor layer so that grassland species were represented, bringing the total number of corridors to 13.

To identify road crossing locations, we ran Factorial Least Cost Paths (FLCPs) across our study area for each species (Cushman *et al.* 2014). FLCPs create pairwise least-cost paths between all source points on the landscape. Due to computational limitations, we reduced the number of source points to 300. We identified probable road crossing locations for each species at the intersection of FLCPs and major roadways in the study area (Cushman *et al.* 2014). These roads included SR-67 as well as SR-52, Interstate 8, Wildcat Canyon Road, Poway Road, and Scripps Poway Parkway. We conducted a point density analysis using the *Point Density Tool* in ArcGIS to determine a distance at which we could aggregate crossing locations into a single crossing zone. We determined that we had greater clustering at a distance of 300 m and created crossing zones around the largest clusters of FLCP points. We then reviewed the crossing zone locations, determined if the zone included an existing structure that could be retrofitted, and made slight placement adjustments to incorporate preexisting structures that had some level of functionality for wildlife movement.

A flow chart depicting the methodological approach for identifying corridors and road crossing locations is provided in Figure 4.

Development of Connectivity Decision Support Tool and Road Crossing Structure Recommendations

We attributed each of the 13 corridors with over 100 variables which we categorized into conservation and management variables, biological variables, and threats and stressors. Conservation and management variables included the conservation status of each corridor, future land use predictions, and cultural sites. Biological variables included attributes such as the multi-species connectivity value as well as connectivity values for each focal species, the presence of threatened and endangered species and other species of interest, and variables describing the composition and configuration of vegetation types. Threats and stressors included levels of development and fragmentation for each corridor, as well as the potential for fire.

We developed a Connectivity Decision Support Tool that incorporates parcel-level data as well as the corridor attributes described above to help managers and planners prioritize areas for acquisition and management. This tool requires planners and land managers to develop a scoring rubric that meets their mandates and can be applied consistently across decision points.

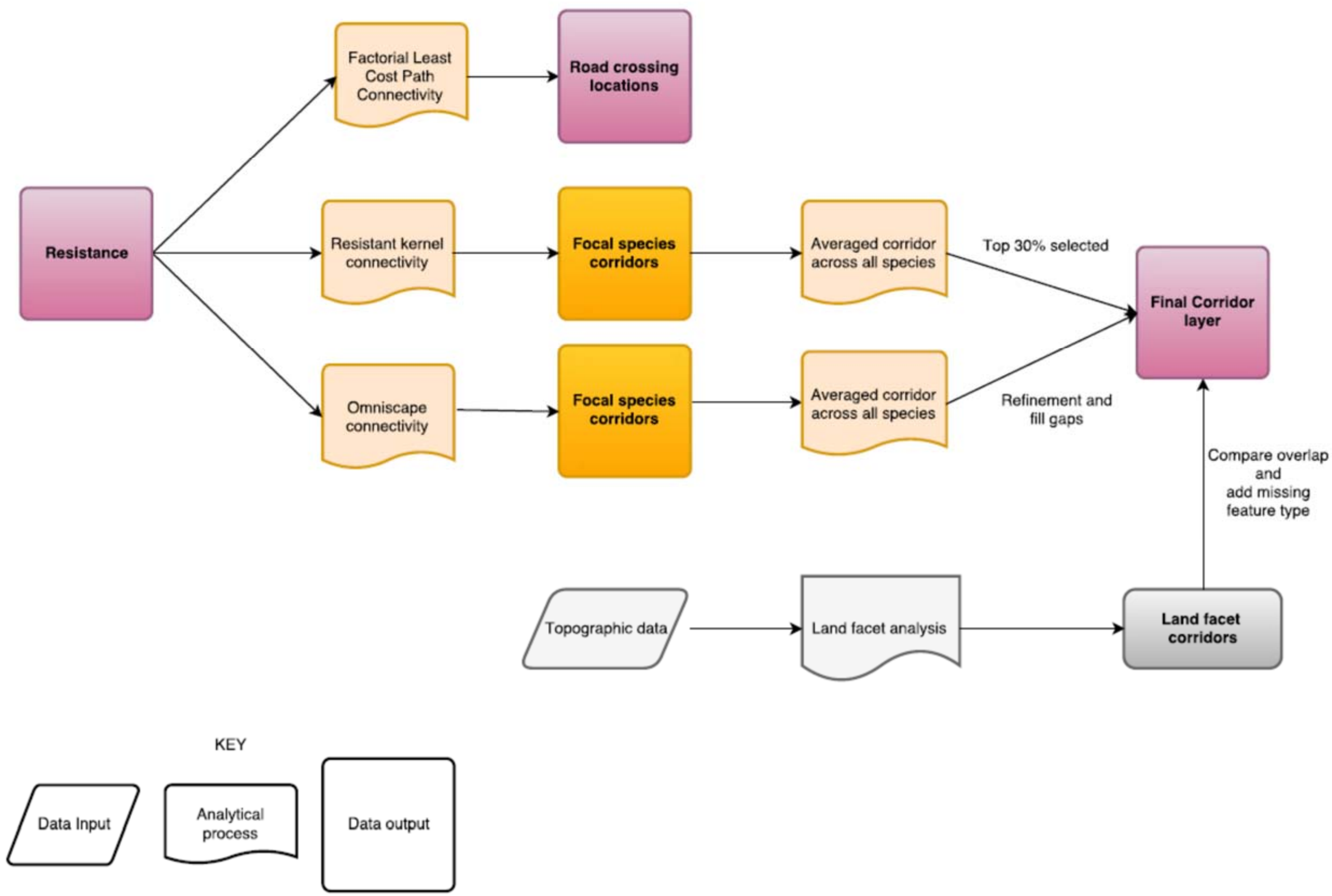

Figure 4. Flowchart of the methodological approach used to develop corridors and identify road crossing locations for the SR-67 area

Road Crossing Recommendation Process

The process we took for identifying road crossing locations and specifications was intended to generate recommendations that were optimal for supporting wildlife movement. This is the first step in the process for developing a fully scoped wildlife crossing infrastructure plan. The recommendations we present here are not cost-constrained and, although we did solicit feedback from Caltrans on our initial recommendations, further refinement will be necessary through collaboration and cooperation with a full team of Caltrans planners including engineers, hydrologists, and biologists. Once site-specific details and tradeoffs have been discussed, the final step will be to estimate costs and further refine the wildlife infrastructure plan based on the available budget.

To ensure our recommendations were appropriate and site-specific we reviewed site characteristics using terrain data, street-view in Google Earth, information from prior data collection, and location knowledge. During this process, we selected one site within each crossing zone (if there was no existing structure within the crossing zone), which we focused on for our design specifications. To identify the need for species-specific design specifications, we reviewed point location data for additional species of interest and identified which species we would want to accommodate at each structure to further inform our crossing structure design recommendations. We completed this by creating buffers around point data for our species of interest based on their dispersal abilities (Table 3). We categorized the size and type of species to be considered in the design of each structure and used a comprehensive literature review on wildlife crossing structure evaluations and guides (Appendix G) to make initial recommendations on crossing structure sizing and type. For each site, we provided recommendations on both the optimal design specifications as well as the minimum with respect to structure type and size. During our literature review, we also identified best management practices to complement the species-specific design recommendations for each crossing structure. We validated our structure recommendations with another site-specific review and added on species-specific design features to provide cover for smaller animals and to enhance connectivity for flying species. We then estimated the minimum length of fencing necessary based on the literature and site conditions to direct species towards structures and away from the roadway.

After completing a draft of these initial recommendations, we solicited input from biologists and a planner at Caltrans. Based on the input we received, we made further refinements and developed a prioritization criterion. To aid decision-making regarding wildlife crossing structure improvement, we added two prioritizations to our crossing structure recommendations. The first was focused on the importance of each site to the suite of wildlife we considered in our analyses. This includes not only the focal species we modeled, but the suite of species stakeholders requested we consider in our multi-species validation. The second prioritization was designed to allow transportation agencies to identify opportunities for near-term improvements based on whether existing crossings could be enhanced through minor alterations. These minor improvements include clearing of sediment and debris in existing crossing structures, enhancing line of sight through the structure, controlling invasive plants in areas surrounding the crossings, restoring native vegetation.

Table 3. Species considered for potential to use proposed road crossings and wildlife corridors. Data sources are as follows: 1) County of San Diego 2016; 2) San Diego Management and Monitoring Program 2016; 3) U.S. Fish and Wildlife Service 2017; 4) Marschalek; 5) BISON 2017 6) GBIF 2017; 7) San Diego Natural History Museum, *In Prep*

Species Common Name	Data source	Movement distance (m)	Movement distance reference
Quino checkerspot butterfly (*Euphydryas editha quino)*	SanBIOS[1], SDMMP[2], CFWO[3]	1,000	USFWS 2003
Arroyo toad (*Anaxyrus californicus)*	SanBIOS[1], SDMMP[2], CFWO[3]	1,082	Brehme and Fisher 2017
Cactus wren (*Campylorhynchus brunneicapillus)*	SanBIOS[1], SDMMP[2], CFWO[3]	1,590	Atwood 1997
California gnatcatcher (*Polioptila californica)*	SanBIOS[1], SDMMP[2], CFWO[3]	3,000	Mock 2004
Stephens' kangaroo rat (*Dipodomys stephensi)*	SanBIOS[1], SDMMP[2], CFWO[3]	400	Price *et al.* 1994
Hermes copper butterfly (*Lycaena hermes)*	SDSU[4], SDMMP[2]	100	Deutschman et al. 2010
Coachwhip (*Coluber flagellum)*	SanBIOS[1], BISON[5], GBIF[6]	1,618	Brehme et al., *Unpublished data*
Granite spiny lizard (*Sceloporus orcutti)*	BISON[5], GBIF[6]	91	Brehme et al., *Unpublished data*
Two-striped garter snake (*Thamnophis hammondii*)	SDMMP[2], BISON[5], GBIF[6]	239	Brehme et al., *Unpublished data*
Western toad (*Anaxyrus boreas)*	SanBIOS[1], BISON[5], GBIF[6]	1,552	Brehme et al., *Unpublished data*
Western whiptail (*Aspidoscelis tigris)*	BISON[5], GBIF[6]	300	Brehme et al., *Unpublished data*
Pallid bat (*Antrozous pallidus)*	SanBIOS[1], SDMMP[2]	2,000	Baker *et al.* 2008
Townsend's big eared bat (*Corynorhinus townsendii)*	SanBIOS[1], SDMMP[2]	10,500	Fellers and Pierson 2002
American badger (*Taxidea taxus)*	SDNHM[7]	1,450	Lindzey 2003
Ringtail (*Bassariscus astutus)*	SDNHM[7]	1,000	Lonsinger *et al.* 2015

RESULTS

Species-specific habitat suitability, resistance, and connectivity

Species-specific habitat suitability and movement models, resistance surfaces, and connectivity outputs are depicted for each of the six focal species in Appendix C. These data products and modeling outputs are available for individual species upon request.

Multi-species Connectivity and Corridor Products

The final corridor connects lands from east to west and north to south across the study area and has an area of 103,838 acres. Figure 5 displays the final multi-species connectivity surface across the study area and Figure 6 displays the final corridor product, which consists of 12 multi-species corridors and one land facet corridor. Currently 35% of the final corridor is comprised of protected lands, 9% is comprised of PAMA land, and 5% is comprised of draft PAMA lands from the Northern San Diego County MSCP. From a modeling study conducted by Butsic *et al.* (2017), we estimate that approximately 10% of the corridor is comprised of developable land (land that has not yet been developed, but has the potential to be developed in the future). Each of the 13 sub-corridors is described in detail in Appendix A.

To aid in the planning and management process, we provided additional spatial products derived from the multi-species connectivity surface: corridor isopleths (Figure 7), a normalized flow surface (Figure 8), and a corridor resiliency map (Figure 9). The normalized flow surface highlights areas of concentrated flow in the outer regions of the study area. In the northeastern part of the study area, this concentrated flow is due to natural features, however, in the northwest and the south, this concentrated flow is due to human development. Areas where flow is impeded mostly coincide with more heavily developed lands. The corridor resiliency map suggests that much of the center of the study area and corridors therein have high resilience to climate change, while corridors in the northeast and southeast of the study area have less resilience.

The conservation and management, biological, and threats and stressor attributes for each of the 13 corridors is provided in Table A1. We describe how each attribute was calculated along with the source of the data used and the minimum and maximum values across corridors. For cross-referencing purposes with the corridor GIS shape file product, we also provide the names of the shape file table that correspond with each attribute.

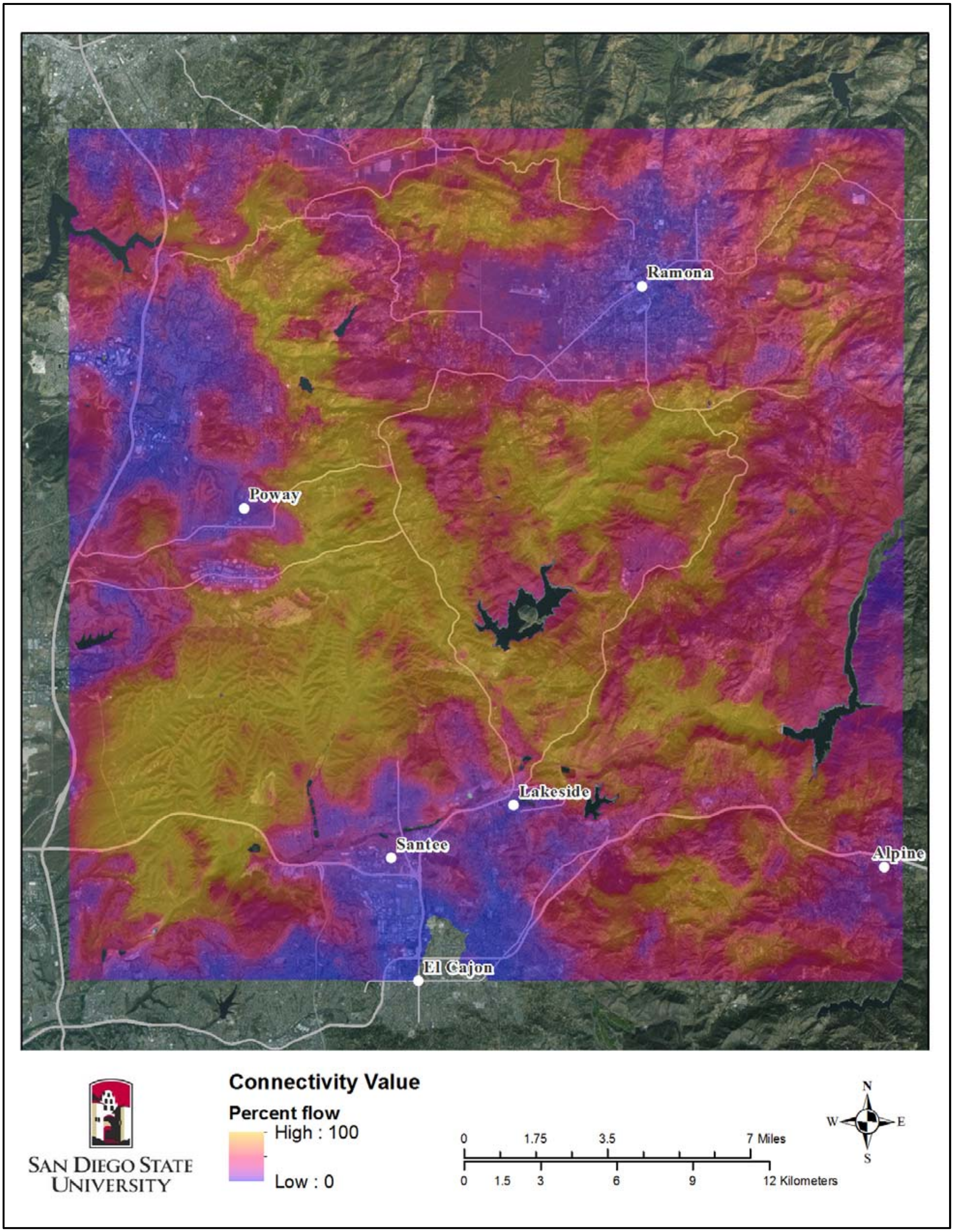

Figure 5. Multi-species connectivity value map depicts percent flow across the study area.

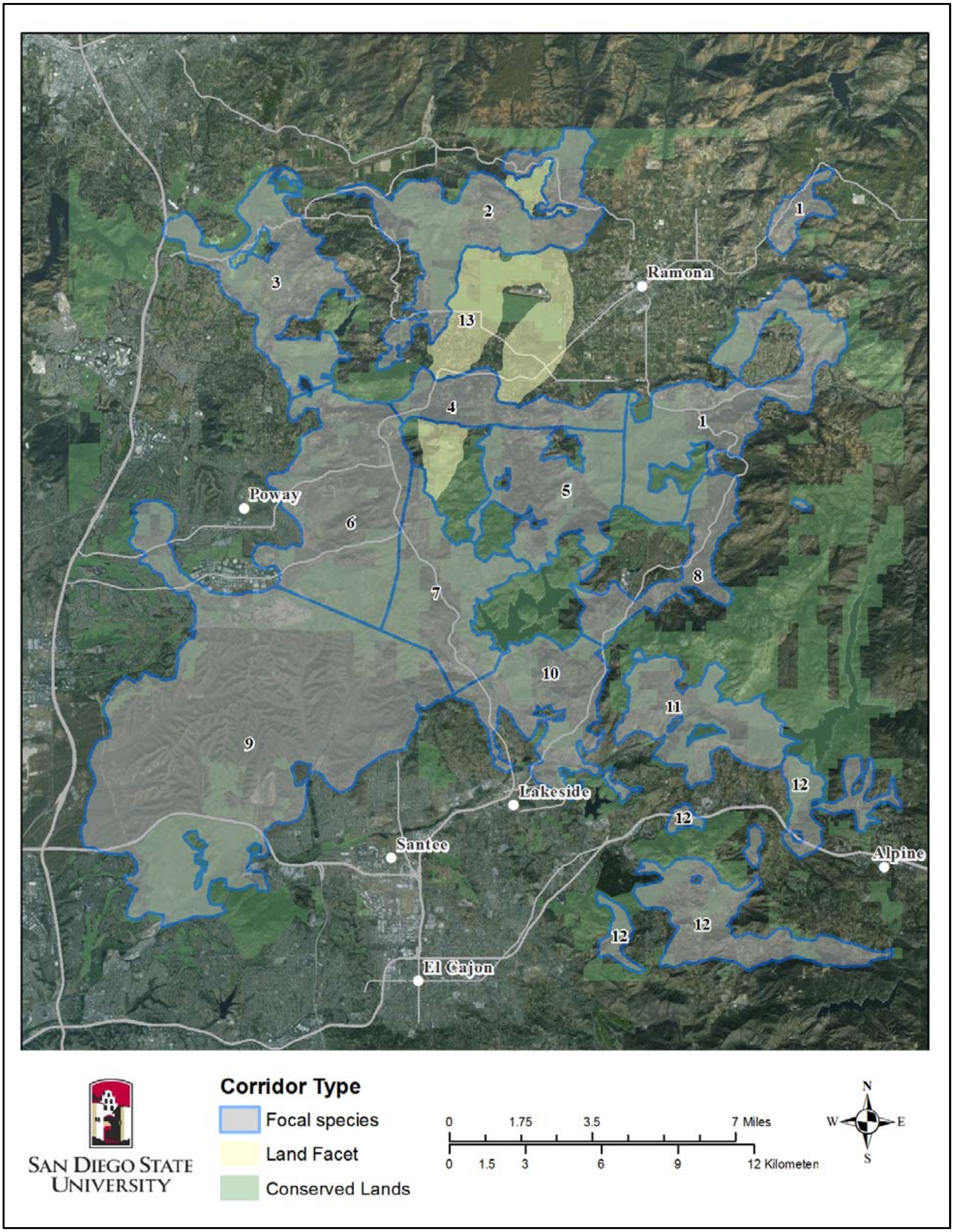

Figure 6. Final combined focal species and land facet corridor map with corridor segments labeled and conserved lands depicted.

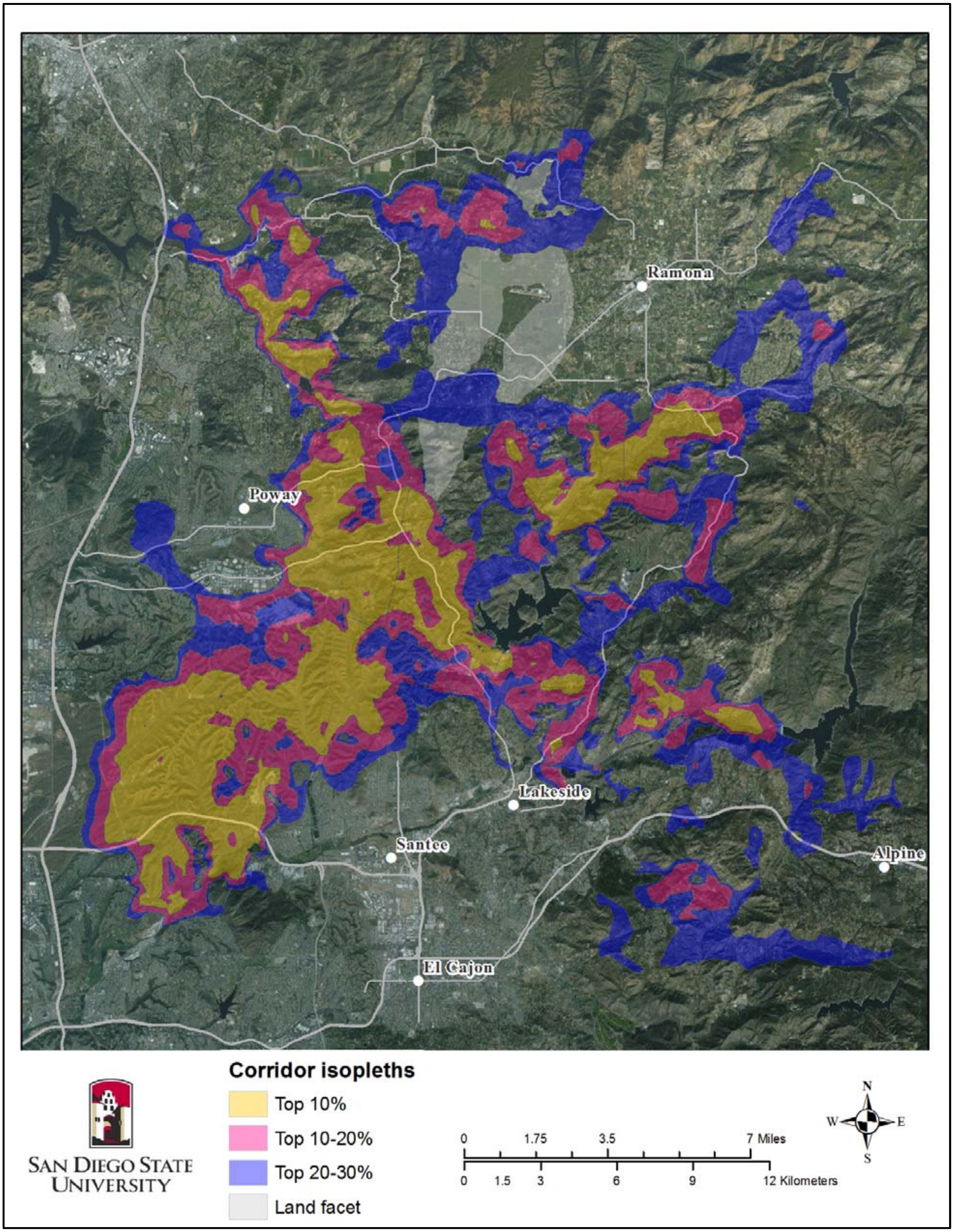

Figure 7. Map of corridor isopleths depicting each corridor broken down into the top 10%, top 10-20%, or top 20-30% of connectivity flow

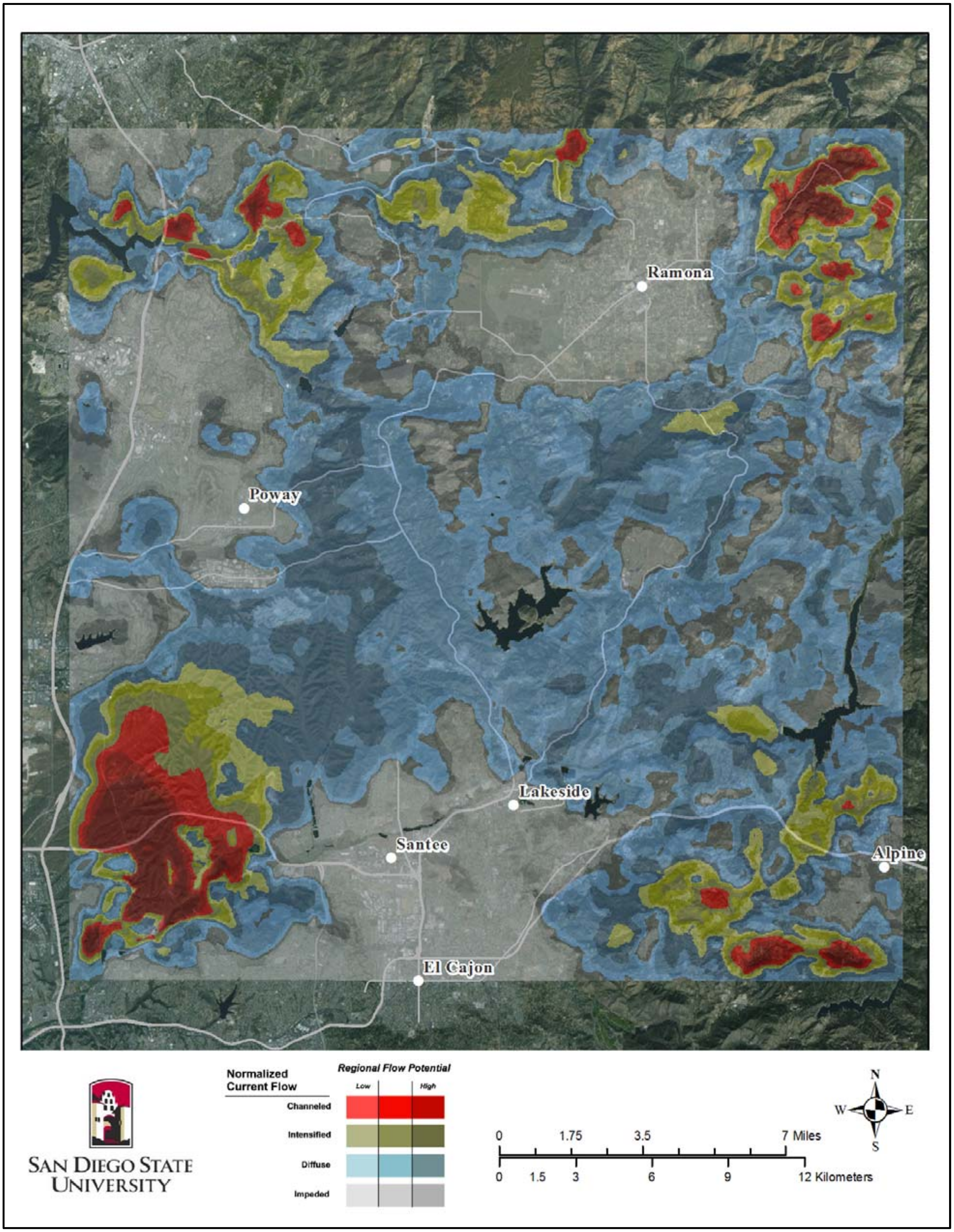

Figure 8. Normalized current flow map that depicts areas where connectivity flow is either channeled, intensified, diffuse, or impeded

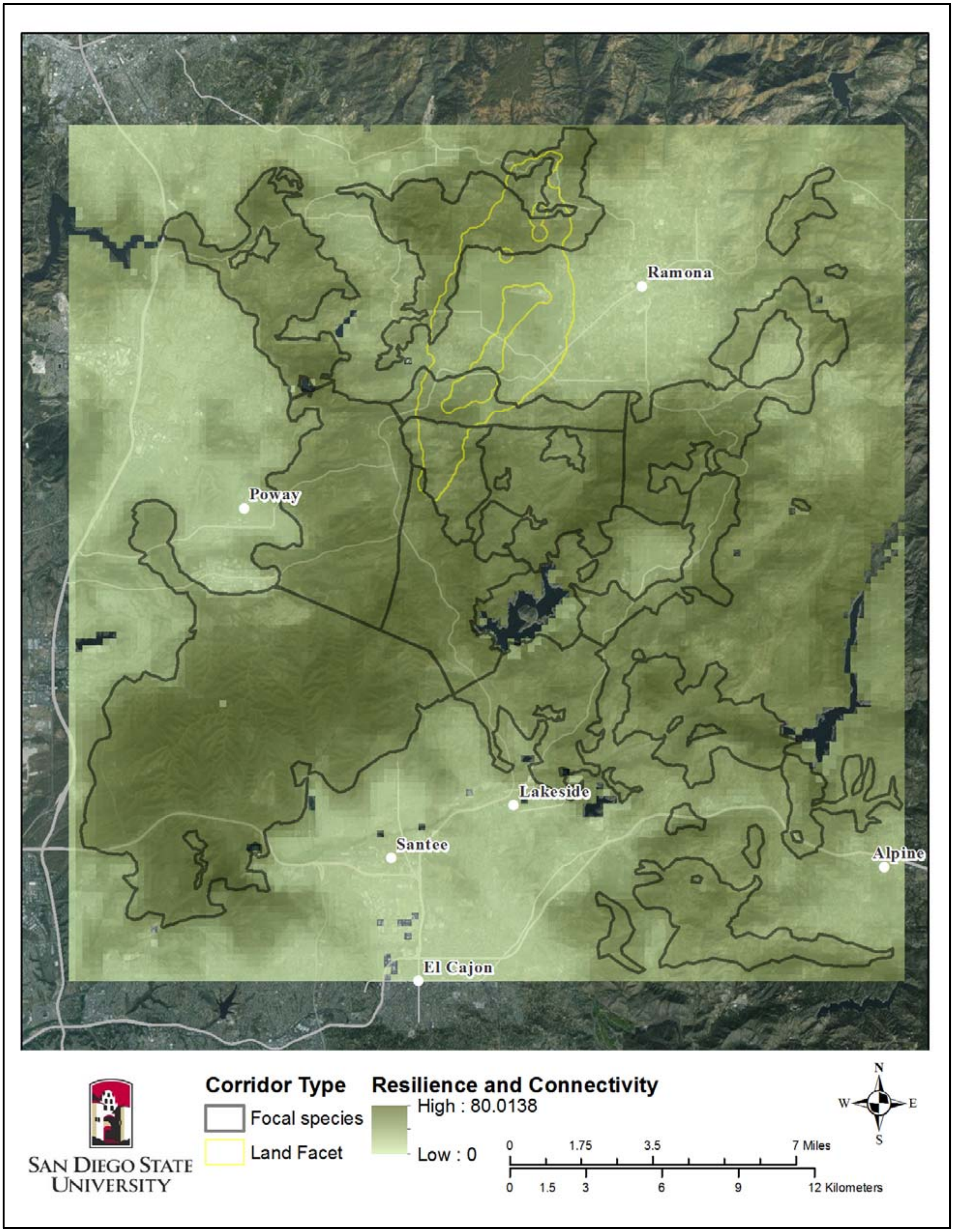

Figure 9. Map of the combined connectivity and resilience to climate change of the study area. Areas of darker green are both more resilient and provide for a greater degree of connectivity

Connectivity Decision Support Tool

The Connectivity Decision Support Tool was designed so that end users can apply a score to a parcel or management site of interest so that parcels and sites can be prioritized across a project. Figure 10 depicts decision points, assessment criteria, and where attributes of the parcel or site of interest might be assigned a score. We developed the support tool so that each land manager / planner could develop a unique scoring system that applies to their management objectives. We reiterate the importance of developing a single scoring rubric that is applied consistently across all decisions.

After identifying a parcel or site of interest, the first decision point is reached. If the site is within a corridor one may decide to move on in the scoring process. If the site is not within a corridor one may decide to examine another site. Then, one might assign a score to the site depending on which corridor isopleth that site falls within. Then, it might be helpful to look at site-specific data. For example, would acquisition be cost-prohibitive or not, what is the area of the parcel, does it fall within PAMA or draft PAMA lands, and by protecting that parcel, how much would that increase the proportion of conserved land in a corridor? Once assessing the parcel specific data, another decision point is reached and one must choose whether to proceed or not. Assuming the parcel still meets management criteria, corridor-specific scores can be applied to the conservation and management variables, biological variables, and threats and stressors of interest. The sum of all the scores results in a final compiled score for the site of interest, which can be compared with other sites for prioritization, acquisition, and management needs.

We have provided a brief example of a scoring rubric and will walk through the application of this rubric using two parcels selected in the study area (Table 4). Our example scoring criteria assigns a score from 1-5 for each variable assessed, with 5 being the best. Both example parcels are in a corridor area. Example parcel #1 is in Corridor 9 and is relatively small in size, whereas parcel #2 is in Corridor 10 and is relatively large. Following along with the Connectivity Decision Support Tool, once we deemed these parcels were in a corridor, we reached the first decision point and decided to move forward. We then noted that parcel #1 is in the middle isopleth (10-20% of the top connectivity values) while parcel #2 is in the top isopleth (the top 10% of connectivity values). We then applied scores to these parcels using our pre-determined scoring criteria. Then we assessed parcel-specific criteria and decided to move on to the corridor attributes. Once we reach this point in the Decision Support Tool, we pulled information directly from the corridor attributes table. We scored two conservation and management attributes, two Biological attributes, and two Threat and Stressors attributes. We then added up the scores for each parcel to obtain a final score. It is worth noting that there are dozens of attributes to select from in developing a scoring criteria and that this is a just a simplified example for illustrative purposes.

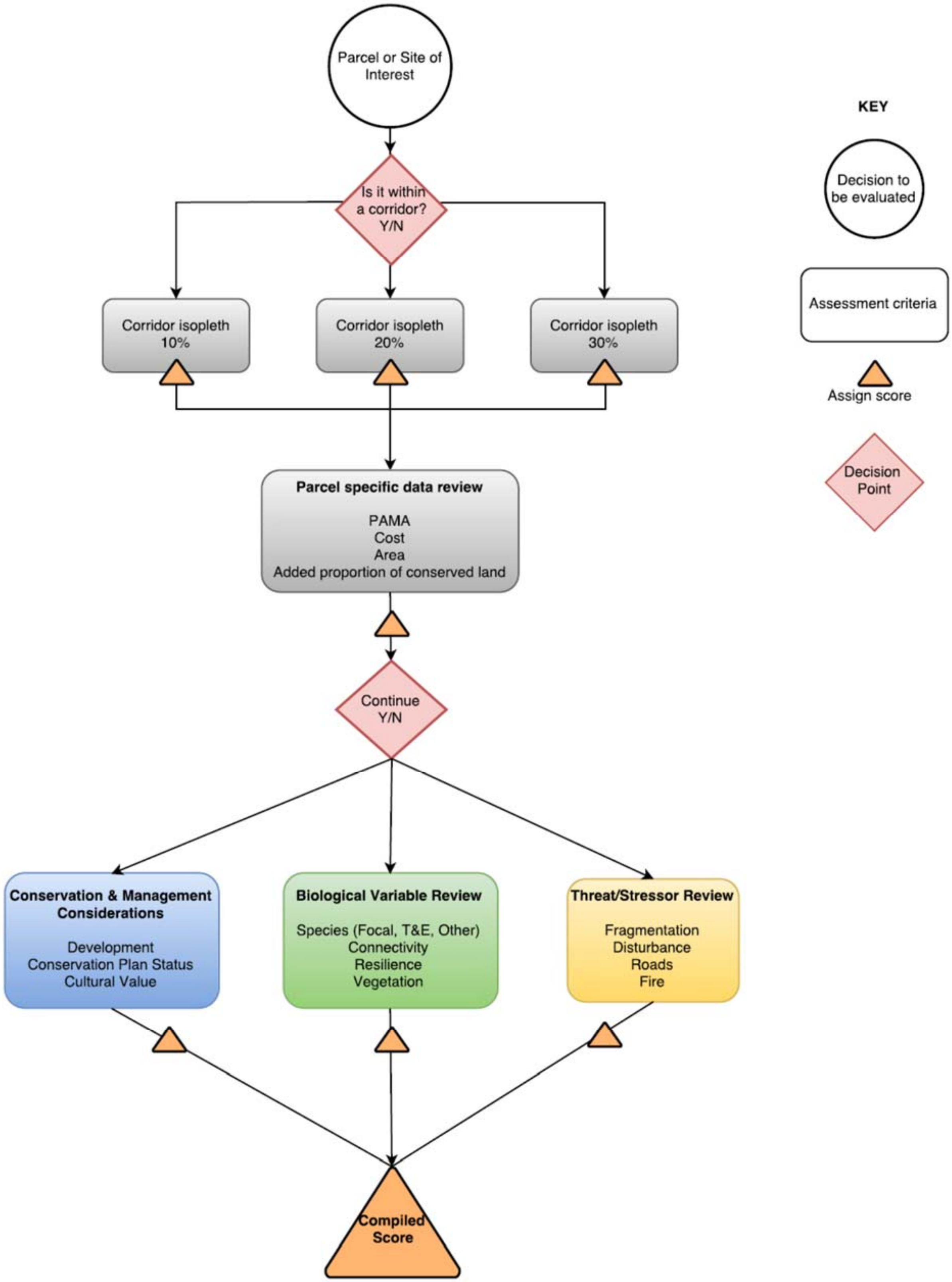

Figure 10. Diagram of the connectivity decision support tool created that depicts decision points, assessment criteria, and scoring guidance

Table 4. Example application of decision support tool to two parcels in the study area. The table provides a simplified version of how one would walk through the process of applying a scoring rubric to compare parcels. Our example scoring criteria assigns a score from 1-5 for each variable assessed, with 5 being the best.

Variable	Scoring criteria	Parcel #1 value	Parcel #1 score	Parcel #2 value	Parcel #2 score
Is it in a corridor?	Y / N	Y, Corridor 10	-	Y, Corridor 9	-
What isopleth is it in?	1 = 20 – 30 % 3 = 10 – 20% 5 = 1 – 10%	10 – 20%	3	1 – 10%	5
Parcel size	1 = small 3 = medium 5 = large	14 acres	3	240 acres	5
Proportion of corridor currently conserved	1 = 15 – 23% 2 = 23 – 31% 3 = 31 – 39% 4 = 39 – 47% 5 = 47 – 56%	30%	2	25%	2
Number of cultural sites	1 = 31 - 105 2 = 106 - 180 3 = 181 - 255 4 = 256 - 330 5 = 331 – 402	126	2	402	5
Whether Arroyo Toad has been detected in that corridor	0 = N 5 = Y	N	0	Y	5
Average multi-species connectivity value in corridor	1 = 68 - 72 2 = 73 – 77 3 = 77 – 81 4 = 81 - 85 5 = 86 – 90	86	5	81	4
Percent of corridor comprised of natural land cover types	1 = 80 - 83 2 = 83 - 86 3 = 86 - 89 4 = 89 - 92 5 = 92 – 96	80	1	89	3
Road density	1 = 6.3 - 5.5 2 = 5.5 - 4.7 3 = 4.7 – 4.0 4 = 4.0 - 3.3 5 = 3.3 - 2.6	6.29	1	5.4	2
Total Score			**17**		**31**

Wildlife Crossing Infrastructure Recommendations

Based on our initial FLCP corridors from our focal species analyses, we identified 176 potential crossing locations (Figure 11). After examining clusters of crossing points within a 300 m buffer distance, we narrowed those 176 locations down to 33 proposed road crossing zones. Of these 33 zones, 12 were along SR-67, three were on SR-52, four were on I-8, seven on Wildcat Canyon Road, one on San Vicente Road, two on Poway Road, and five on Scripps Poway Parkway. After determining whether there was already an existing structure at or near the crossing zones and attributing these with data on topography, vegetation composition, and our 17 validation species as well as our original six focal species, we performed a site-specific review and identified a proposed crossing site. If there was an existing structure at the site, we targeted it for a retrofit at the present site, otherwise we recommended new siting. At two of the locations on Scripps Poway Parkway, the topography and road cut was deemed to be prohibitive for placement of a wildlife crossing structure in the recommended zone or adjacent to it. We therefore eliminated those two locations from our final site recommendations bringing our site recommendations down to 31 locations. However, based on prior culvert monitoring data collected during an earlier study for Caltrans (Jennings and Lewison 2016), we noted that there were two existing culverts on SR-67 that were functioning for some species that were not incorporated into our initial 33 zones. We incorporated those two existing culvert locations into our proposed crossing site recommendations for a total of 33 sites (Figure 12).

On SR-67, the primary focus of our wildlife crossing infrastructure recommendations, we identified and prioritized 14 crossing sites (Table 5). All but one of these locations has an existing structure that could be retrofitted. Of those sites, six could be improved with minor effort whereas the remaining eight would require major redesign to facilitate wildlife movement. We identified four sites along the highway that were of extremely high importance to wildlife movement, six that were of high importance, and four that were of moderate importance. Sites targeted for minor improvements only fell within our high and moderate importance categories for wildlife movement. Site specific details for each of the recommendations for wildlife crossing structures on SR-67 as well as the recommendations on the other major roads in our study area can be found in Appendix B.

Based on a thorough review of the literature and input from Caltrans as well as our stakeholder group, we identified 25 best management practices to be incorporated into the wildlife infrastructure planning for SR-67 (Table 6). We classified these by the type of recommendation into seven categories related to conservation planning, design of structures, barriers, fencing, and material selection, and construction and maintenance considerations.

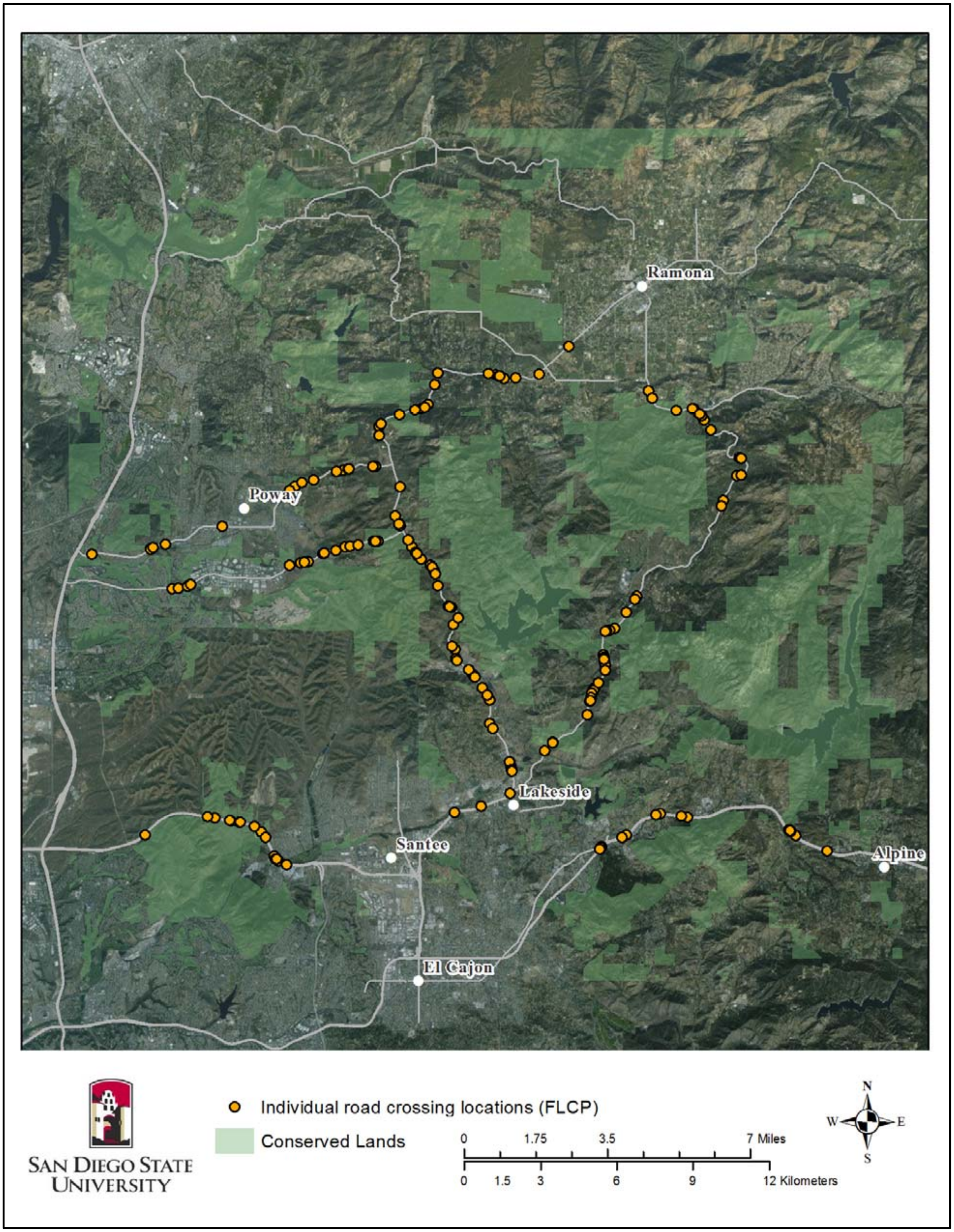

Figure 11. Map of potential road crossing locations identified from the factorial least cost path connectivity modeling (FLCP).

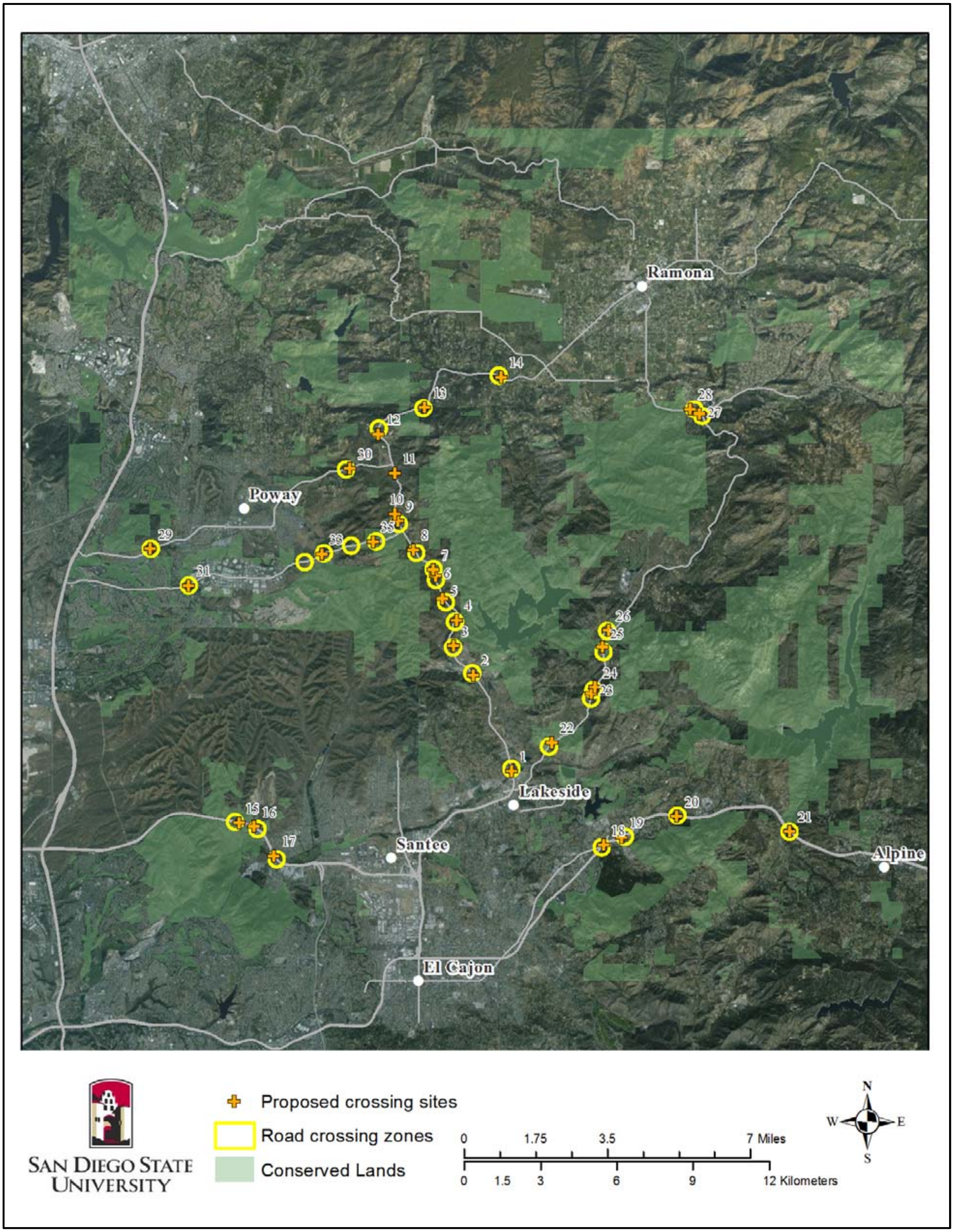

Figure 12. Map of potential road crossing locations identified from the factorial least cost path connectivity modeling (FLCP)

Table 5. Wildlife crossing infrastructure recommendations for SR-67

Site ID	Wild-life Priority	Improve-ment Type	Rd width (ft)	Right-of-way (ft)	Optimal Crossing Type	Minimum Crossing Type	New, Retro, or Exists	Optimal width (ft)	Optimal height (ft)	Min width (ft)	Min height (ft)	Existing diameter (ft)	Min fence length E or S (ft)	Min fence length N or W (ft)
1	2	Minor	45.9	164.0	Bridge		Exists	–	13.1	–	9.8	NA	–	–
2	3	Minor	114.8	141.1	Arched or box culvert	Pipe culvert	Retrofit	13.1	9.8	7.0	–	7.0	590	656
3	1	Major	164.0	502.0	Arched or box culvert		Retrofit	26.2	14.8	19.7	13.1	4.0	1,312	1,476
4	2	Major	101.7	150.9	Arched or box culvert		Retrofit	16.4	9.8	13.1	6.6	1.5	1,640	2,460
5	3	Major	144.4	150.9	Pipe culvert		Retrofit	6.6	–	3.3	–	3.0	820	328
6	1	Major	131.2	150.9	Arched or box culvert		Retrofit	26.2	14.8	19.7	13.1	7.5	984	1,312
7	2	Minor	85.3	157.5	Arched or box culvert	Pipe culvert	Retrofit	13.1	9.8	7.5	–	7.5	1,312	2,624
8	3	Minor	88.6	141.1	Arched or box culvert	Pipe culvert	Retrofit	13.1	6.6	6.6	–	3.0	771	1,082
9	1	Major	170.6	160.8	Arched or box culvert		Retrofit	26.2	14.8	16.4	9.8	5.5	1,148	820
10	2	Minor	55.8	150.9	Arched or box culvert	Pipe culvert	Retrofit	13.1	9.8	7.0	–	7.0	1394.4	820.2
11	2	Minor	55.8	150.9	Arched or box culvert	Pipe culvert	Retrofit	13.1	9.8	8.5	–	8.5	1378.0	2296.6
12	2	Major	82.0	150.9	Arched or box culvert	Pipe culvert	Retrofit	13.1	6.6	6.6		3.0	1804.5	1804.5
17.61	1	Major	114.8	311.7	Wildlife overpass		New	229.7		164.0				
20.17	3	Major	82.0	114.8	Arched or box culvert	Pipe culvert	Retrofit	13.1	6.6	6.6		3.0		

Table 6. Wildlife crossing infrastructure best management practices recommendations

Type	Best Management Practices Recommendations
Barriers	If median barriers are installed or the k-rails along the section of SR-67 just north of Vigilante Road remain, stagger placement and installing scuppers to allow wildlife to pass through if they become trapped in the roadway
Conservation	Work to acquire parcels on either side of the road at all crossing locations
Conservation	Work to acquire parcels to connect conserved lands on either side of crossing locations
Construction	Implement mitigation measures to protect wildlife from wildlife-vehicle collisions and impacts during construction
Construction	Implement a BACI study to monitor efficacy of structures beginning prior to construction
Crossings	Maintain small culvert structures for small animal use at intervals of ~90m (300 feet). Structures should have diameter of 0.5 - 1.5m
Crossings	Target an average of 1 crossing per 2 km (1.2 mi) of roadway for medium to large animals
Crossings	Ensure structures have a straight alignment with no bends or curves; there should be a continuous line of sight
Crossings	If hydrological issues preclude optimal structure design for wildlife, consider dual siting of structures for drainage and wildlife movement
Fencing	Bury fencing several inches to prevent digging underneath
Fencing	Construct fence lip to prevent climbing/jumping over
Fencing	Ensure fence ends are tied into existing barriers (topographic or anthropogenic) wherever possible. If none exist, consider adding boulders or a berm to block access and line of sight
Fencing	Construct longer fences for funneling wildlife to crossing structures where possible (especially for large mammals)
Fencing	Construct walls or fencing high enough to encourage flight up and over traffic to avoid bird-vehicle collisions, possibly with flagging added for visibility
Fencing	Install jump outs at regular intervals based on length of fencing segments
Fencing	Conduct roadkill monitoring after crossing construction to determine if extended fencing or jump outs are necessary
Fencing	Once final fencing lengths have been determined, identify locations for jump outs to allow wildlife to exit the roadway if they become trapped. Recommend jump outs at 1/2 mile spacing if there in uninterrupted fencing
Fencing	Consider working with home owners to install gates or cattle guards at driveways to improve the functionality of fencing
Fencing	If gates and cattle guards on driveways are not possible, consider fence turn arounds to redirect animals. Recommend revisiting literature for new driveway fencing guidelines prior to the finalizing fencing plan.
Fencing	Place fencing as close to roadway as possible (rather than at the ROW) to limit wildlife crossing fencing to reach attractive habitat on the other side
Maintenance	Maintain structures free of sediment and debris build up; remove invasive and native vegetation that block access or line of sight through structure
Material	Native surface bottoms when possible
Material	Use noise dampening structure materials
Material	Avoid zinc coating if crossing is to be made of metal
Material	Consider limiting the use of rip rap at structure entrances where possible to facilitate use by small animals

Discussion

Through a comprehensive, multi-species connectivity analysis using robust analytical approaches, we created a connectivity plan, implementation guidance through a decision support tool, and a wildlife crossing infrastructure plan for key roadways in our study area. Through this data-driven approach, we:

- Assembled a multi-species connectivity analysis using a suite of data types and species complemented by a landscape-focused land facet analysis
- Analyzed a suite of data types using cutting-edge analytical techniques appropriate to each data type
- Leveraged survey and monitoring data from our study region, producing a data-informed connectivity plan without the collection of any new field data
- Identified and mapped 12 spatially-explicit focal species corridors and one land facet corridor to facilitate wildlife movement within the SR-67 region of San Diego's Multiple Species Conservation Plan area
- Assessed the potential functionality of those corridors for additional species including five federally listed species and 13 other species of interest
- Attributed those spatially-explicit corridors with data on land conservation status, biological variables, and threats and stressors to inform decision-making
- Created a decision support tool for scoring potential acquisitions, habitat restoration projects, or other land management and planning decisions
- Used our connectivity models, species data, site specific information, and past data collection on crossing use and roadkill to inform wildlife crossing infrastructure recommendations for SR-67 as well as other roadways within our analysis area
- Worked with a variety of stakeholders throughout this process to gather information, feedback, and key input to generate a connectivity plan and conservation tool that could readily be implemented by the diverse range of land management and planning entities working in this region of San Diego County

Application of the Connectivity Plan

The data products we developed during this project are intended to be used in planning for subregional connectivity between core complexes of the preserve network of the MSCP and the draft NCMSCP. This information can be applied to connectivity planning and implementation decision-making, particularly when considering connectivity as a key component of reserve design. The focal species approach as well as the species we selected was intended to identify corridors to provide connectivity for preserving biodiversity for the most species. By linking additional quantitative metrics to our corridors, we strived to facilitate acquisition decision-making, the identification of restoration targets to improve connectivity, and to aid in end-users in the evaluation of the potential impacts of development projects on wildlife connectivity in this region.

Although our focal species approach provides specific information about connectivity for the six species we used throughout our modeling process, the data we present here is not appropriate for use in single-species conservation planning or decision-making, particularly those species that are narrow habitat specialists such as those species reliant on native grasslands or vernal pools.

Our analyses and results are also not suitable for assessing connectivity for extreme dispersal-limited species that may move within a core, but not among core preserve areas. Finally, although we did model connectivity irrespective of the delineation of conserved lands, our final products are not appropriate for use in making determinations about core habitat, *e.g.*, habitats important for foraging or breeding, other than the importance of those areas to wildlife movement on a landscape scale.

Decision Support and Implementation

We have provided a suite of data products to support the use of this information in many different management and planning scenarios. By generating geospatial data on our corridor extents to represent the entire corridor area as well as isopleths of the top 10%, 20%, and 30% of connectivity flow for our focal species, we have considered the need for management options in different decision-making circumstances. To highlight the areas of greatest conservation need with the most channelized flow, we have generated a normalized flow surface to pinpoint locations where natural or anthropogenic features constrict connectivity. We have also provided options for end users to consider conserving resilience to climate change both through the land facet corridor analysis we performed, and by combining a resilience surface (The Nature Conservancy, San Francisco, CA, unpublished) with our multi-species connectivity surface.

Through our engagement with stakeholders, we identified an array of variables to facilitate use in planning and decision-making at many levels. We considered factors related to land conservation and management such as the conservation status within each corridor and targets under the NCCP plan. We also incorporated projections of future land use and development potential in our corridor attribution. To explore the potential co-benefits of the conservation of lands for connectivity and engage potential tribal stakeholders, we assessed a measure of cultural value by accounting for the number of archaeological sites, isolated artifacts, and historic structures within each corridor. To account for the range of biological variables relevant to our corridors, we calculated the modeled connectivity value of each segment for our focal species as well as the connectivity potential for five species listed under the Endangered Species Act and an additional 13 species of interest identified by the stakeholder group. We also evaluated the connectivity of different vegetation types within each corridor. Finally, we considered several threats and stressors in our corridor review. We accounted for fragmentation by calculating metrics such as the edge-to-interior ratio and intactness values as well as road density and the proportion of the corridor that had been developed. Metrics related to fire risk and increasing fire frequency were also incorporated into our corridor assessment.

In addition to providing relevant data for implementation of this connectivity plan, we also created a decision support tool to demonstrate how end users might apply the information provided about these corridors to their decision-making processes. Our worked example demonstrates how an organization might go about assigning their scoring criteria prior to decision making and continue through the process to determine whether land acquisition, habitat restoration, or conversely, development may or may not meet management goals and objectives related to connectivity. The example provided is not prescriptive, and we recommend that each organization carefully consider how to assign scoring prior to initiating use and then proceed to use that scoring process consistently. This type of decision support tool allows for transparency in the decision-making process and can lend quantitative backing to justify decisions that may require external support.

The wildlife crossing infrastructure plan we designed through this project is just the first phase in the process of designing a full infrastructure plan for SR-67 or other roadways in the study area. Implementation of a wildlife crossing plan will require further engagement with the full complement of Caltrans staff (including engineers, hydrologist, biologists, and planning) for review and planning. What we have established is a starting point informed by the data and our models that targets an optimal design for wildlife movement given the species, topography, and habitat. Although we did get initial feedback and guidance from Caltrans on our preliminary recommendations, the structure specifications we have provided are not cost-constrained and have not undergone full review by a transportation planning team. However, to facilitate that next step, we have added our two levels of prioritization, wildlife importance and improvement type, to the crossing structure recommendations we have made in this report. We believe these prioritizations should help guide discussions to improve the permeability of SR-67 for wildlife.

Future Applications

The science and statistical approaches for evaluating wildlife space-use, movement, and connectivity is constantly evolving and improving. Our ability to use a wider range of data to assess and plan for landscape connectivity has grown in recent years and now presents opportunities to expand on prior regional connectivity plans to address wildlife movement and barriers to that movement at different spatial and temporal scales. The products we have created for the SR-67 region illustrate how spatially-explicit corridors can be linked to the organization and guidance of management plans so they are directly connected with management actions and decision-making rather than standing out as a separate management task to be executed. Through this project, we have developed a model for utilizing commonly available biological data to design and implement a comprehensive multi-species connectivity plan. The analysis and implementation plan we have assembled here can readily be adapted to different regions, scenarios, species, and habitats to facilitate planning at many levels and should be applied more broadly to advance data-informed planning and management actions.

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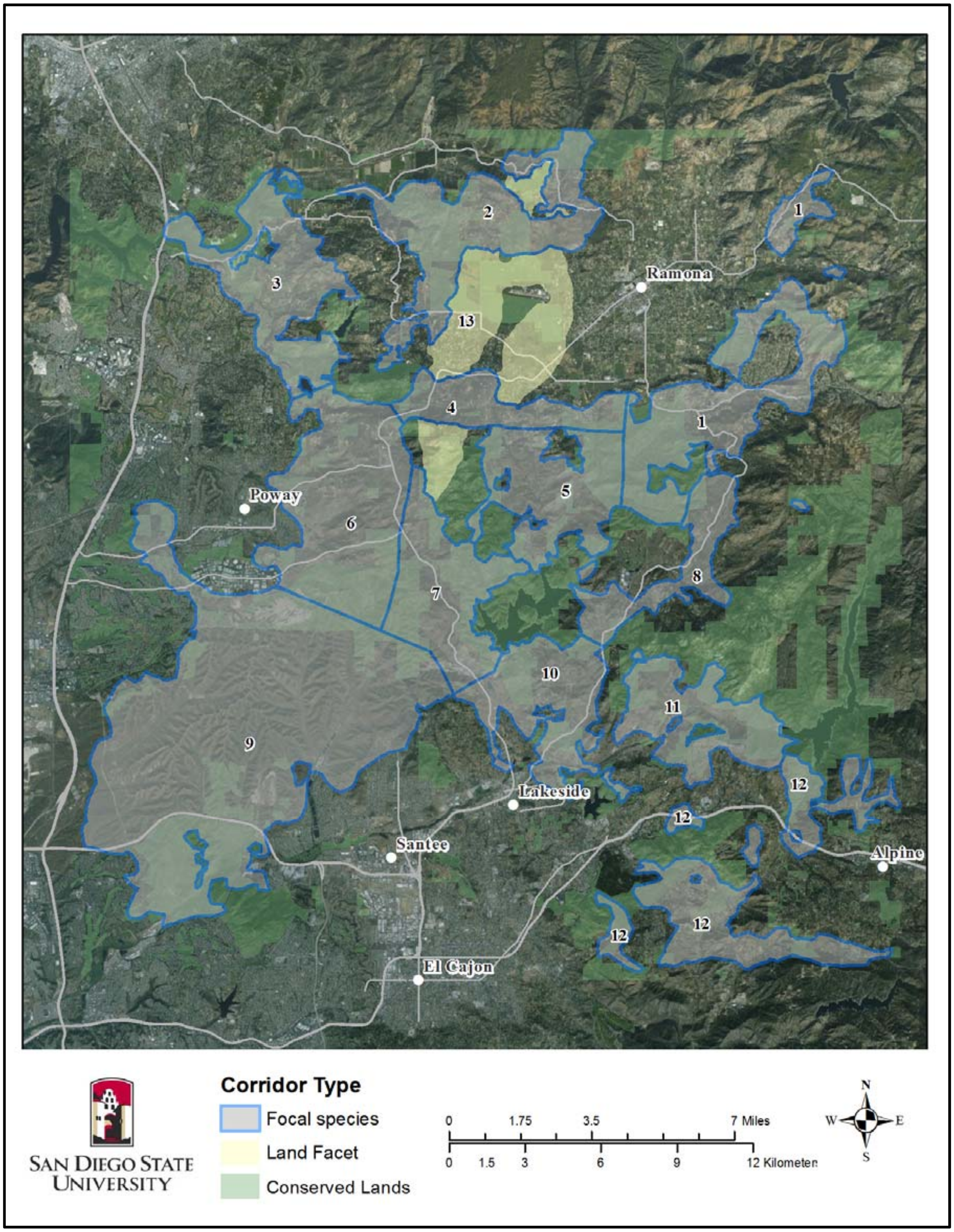
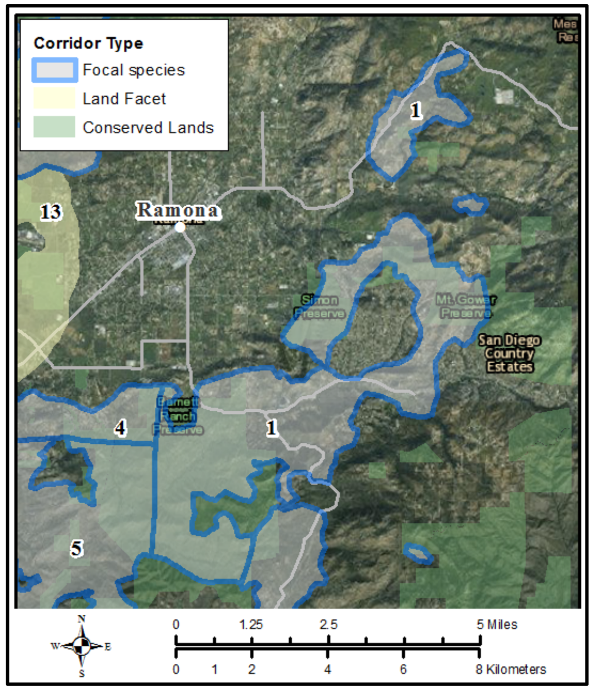
APPENDIX A. CORRIDOR SEGMENT MAPS AND DESCRIPTIONS AND CORRIDOR METADATA TABLE





Corridor 1

8,233 acres

46% conserved

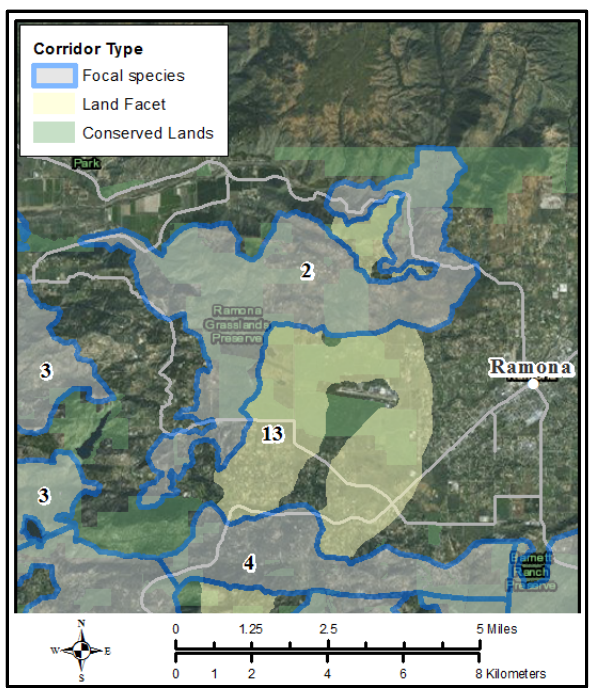
1% PAMA

32% Draft PAMA

Average connectivity value: 76

Corridor 1 is on the east side of the study area and runs just south of the developed lands of the city of Ramona. It provides connectivity from the Mesa Grande Reservation to the Barnett Ranch Preserve and is the only connection to the northeastern corner of the study area. This corridor also contains two important road crossing zones on Wildcat Canyon Road. The northernmost section of this corridor is in the outer isopleth (top 20-30% of connectivity values) and has highly channelized flow, indicating connectivity is restricted.

Eighty-five percent of this corridor is comprised of natural land cover types and two out of the five threatened and endangered species assessed are present here. Land cover types with good connectivity across this corridor include chaparral, coastal sage scrub, hardwood forest and riparian. Developable parcels make up 10% of this corridor.



Corridor 2

7,579 acres

43% conserved

6% PAMA

13% Draft PAMA

Average connectivity value: 72

Corridor 2 is in the north-central part of the study area and encompasses much of the Ramona Grasslands preserve. It connects Cleveland National Forest lands in the northern part of the study area with Mt. Woodson in the south. Flow through this corridor is channelized in the very north, at its connection with the Cleveland National Forest, and then becomes more diffuse further south at Mt. Woodson. One of the critical connections of this corridor, from the Ramona Grassland Preserve to Mt. Woodson, is in the outer isopleth (top 20-30% of connectivity values).

Eighty-eight percent of this corridor is comprised of natural land cover types and four out of the five threatened and endangered species assessed are present here. Land cover types with good connectivity across this corridor include chaparral, coastal sage scrub, and riparian. Developable parcels make up 14% of this corridor.

Corridor 3

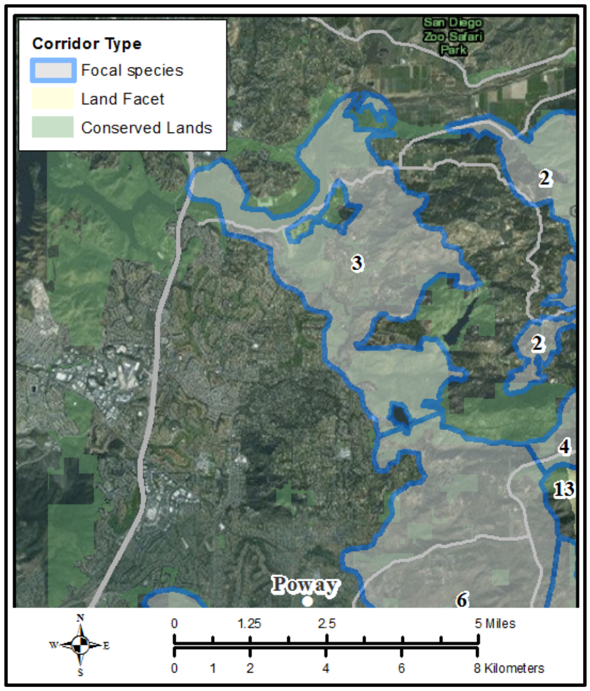
6,141 acres

50% conserved

4% PAMA

3% Draft PAMA

Average connectivity value: 84



Corridor 3 connects the San Dieguito River in the north with Lake Poway Recreation Area and the Blue Sky Ecological Reserve in the south. Though this corridor is mostly comprised of the inner two isopleths (top 1-20% of connectivity values), it has areas of highly channelized flow leading up to and along the San Dieguito River. Corridor 3 also has a narrow section (3,300 feet wide or less) south of the Maderas Golf Club along Old Coach Road that is vulnerable to fragmentation.

Eighty-three percent of this corridor is comprised of natural land cover types and three out of the five threatened and endangered species assessed are present here. Land cover types with good connectivity across this corridor include coastal sage scrub and riparian. Developable parcels make up 19% of this corridor.

Corridor 4

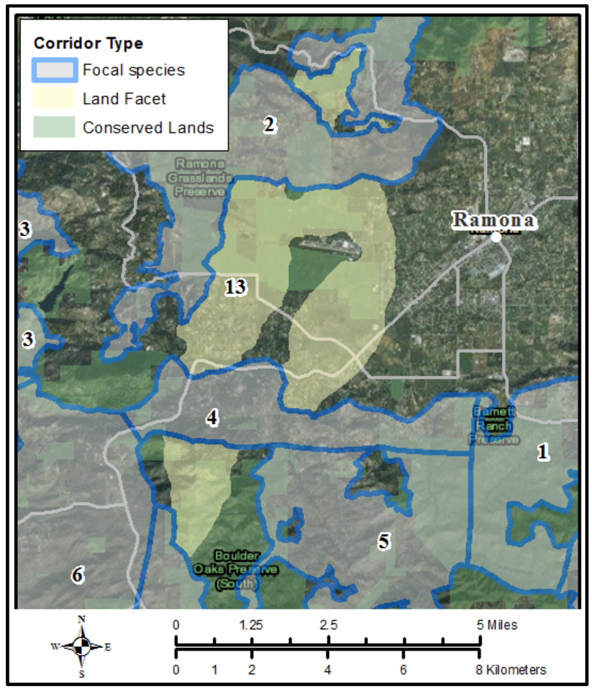
3,205 acres

18% conserved

1% PAMA

5% Draft PAMA

Average connectivity value: 70



Corridor 4 provides east-west connectivity from Mt. Woodson, across SR-67 to the Barnett Ranch Preserve. This corridor is mostly comprised of the outer isopleth of connectivity values (top 20-30% of connectivity values). Corridor 4 contains two important wildlife road crossing zones along SR-67.

Eighty-four percent of this corridor is comprised of natural land cover types and one out of the five threatened and endangered species assessed is present here. Land cover types with good connectivity across this corridor include chaparral and hardwood forest. Developable parcels make up 39% of this corridor.

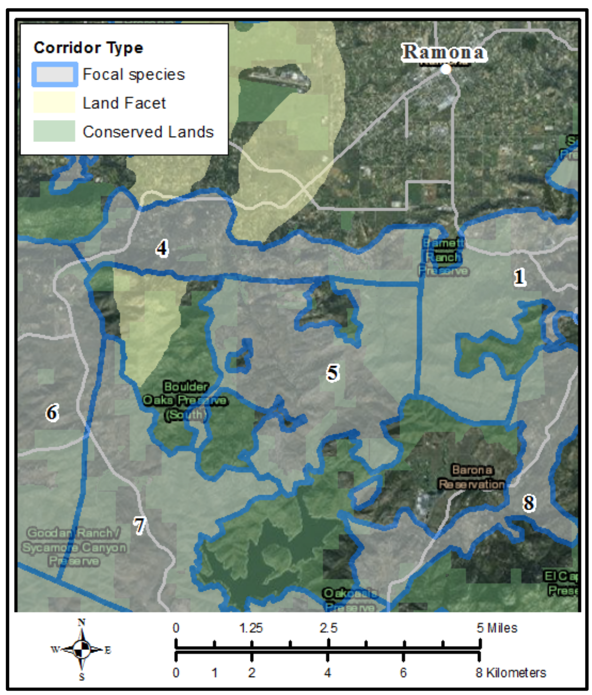
Corridor 5

5,518 acres

46% conserved

25% PAMA

Average connectivity value: 86



Corridor 5 is in the center of the study area between Boulder Oaks Preserve to the west and Barnett Ranch Preserve and Cañada de San Vicente to the east. Developable parcels make up 41% of this corridor. Corridor 5 is comprised of areas with diffuse flow, but has one pinchpoint between the north and south segments of the Boulder Oaks Preserve that measures only 750 feet across. This arm of the corridor is in the outer isopleth (top 20-30% of connectivity values).

Ninety-six percent of this corridor is comprised of natural land cover types and two out of the five threatened and endangered species assessed are present here. Land cover types with good connectivity across this corridor include chaparral, hardwood forest, and riparian.

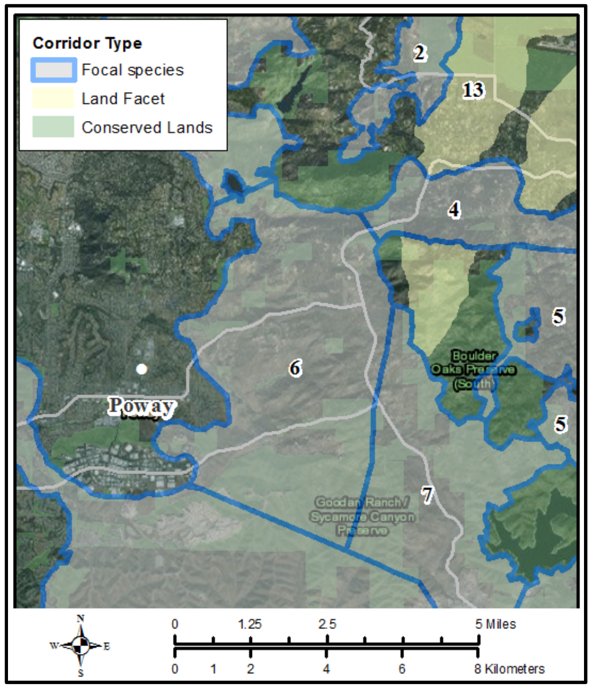
Corridor 6

9,422 acres

33% conserved

10% PAMA

Average connectivity value: 90



Corridor 6 is a fairly wide and intact north-south corridor connecting Mt. Woodson in the north with Sycamore Canyon. This corridor has diffuse flow and is mostly comprised of the top two connectivity isopleths (top 1-20% of connectivity values. Corridor 6 contains two important wildlife road crossing zones on SR-67, one on Poway Road, and three on Scripps-Poway Road.

Eighty-eight percent of this corridor is comprised of natural land cover types and one out of the five threatened and endangered species assessed is present here. Land cover types with good connectivity across this corridor include chaparral, coastal sage scrub, and grassland. Developable parcels make up 41% of this corridor.

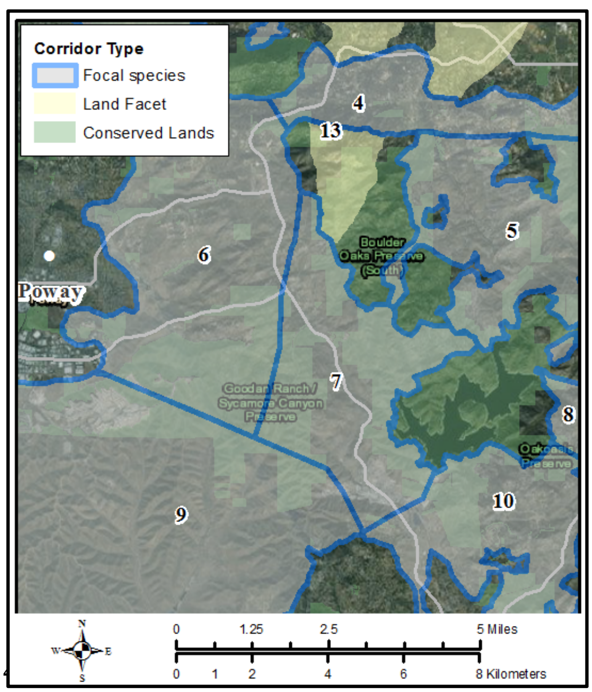
Corridor 7

5,599 acres

56% conserved

10% PAMA

Average connectivity value: 86



Corridor 7 provides connectivity from the San Vicente Highlands and Boulder Oaks preserves on the east side of SR-67 to Sycamore Canyon and Goodan Ranch Preserves on the west side. This corridor contains seven important wildlife road crossing locations on SR-67. Corridor 7 is mostly made up the top two corridor isopleths (top 1-20% of connectivity values), however there is one important arm of east-west connectivity north of the San Vicente Reservoir that is in the outer corridor isopleth (top 20-30% of connectivity values).

Ninety percent of this corridor is comprised of natural land cover types and two out of the five threatened and endangered species assessed are present here. Land cover types with good connectivity across this corridor include chaparral, coastal sage scrub, and grassland. Developable parcels make up 34% of this corridor.

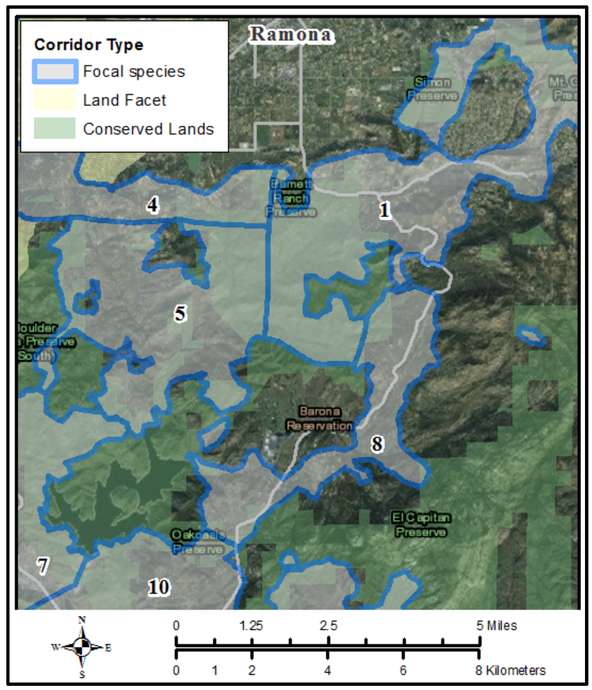
<u>Corridor 8</u>

3,143 acres

15% conserved

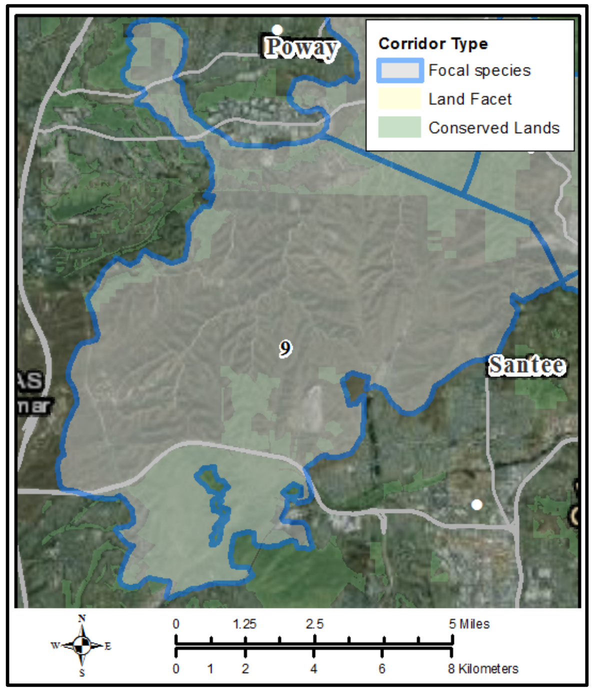
4% Draft PAMA

Average connectivity value: 78



Corridor 8 connects the Barona Reservation and Cañada de San Vicente Preserve in the northeast with the Oakoasis Preserve in the southwest. It is comprised of diffuse flow and the out two corridor isopleths (top 10-30% of connectivity values). Compared with other corridors in the study area corridor 8 is narrow and has a pinch point that measures only ~2,600 feet wide. Corridor 8 also contains one important wildlife road crossing location on Wildcat Canyon Road.

Ninety-four percent of this corridor is comprised of natural land cover types. None of the endangered species assessed are present in this corridor. Land cover types with good connectivity across this corridor include chaparral and hardwood forest. Developable parcels make up 8% of this corridor.



Corridor 9

27,849 acres

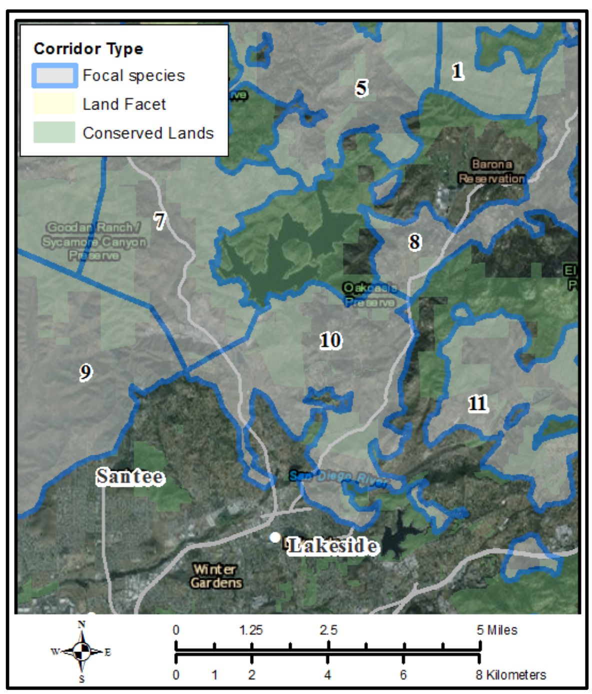
25% conserved

2% PAMA

Average connectivity value: 87

Corridor 9 is the largest corridor and connects Sycamore Canyon and Goodan Ranch Preserves in the north with Mission Trails Regional Park in the south. Marine Corps Air Station Miramar is a major land owner in this corridor. Corridor 9 contains diffuse flow in the north, but transitions to highly channelized flow in the south. It is mostly comprised of the top two corridor isopleths (top 1-20% of connectivity values). Corridor 9 has one important wildlife road crossing location on Poway Road, one on Scripps-Poway Parkway, and two on SR-52.

Eighty-nine percent of this corridor is comprised of natural land cover types and three of the five endangered species are present here. Land cover types with good connectivity across this corridor include chaparral, coastal sage scrub, and grassland. Developable parcels make up 9% of this corridor.



Corridor 10

5,211 acres

30% conserved

24% PAMA

Average connectivity value: 81

Corridor 10 connects the San Vicente Reservoir and the Oakoasis Reserve in the north with the San Diego River and Lake Jennings in the south. It contains diffuse flow and is comprised mostly of the outer two corridor isopleths (top 10-30% of connectivity values). It contains one important wildlife road crossing location on SR-67 and one on Wildcat Canyon Road.

Eighty percent of this corridor is comprised of natural land cover types, and two of the five endangered species assessed are present. Land cover types with good connectivity across Corridor 8 include chaparral, coastal sage scrub, and riparian. Developable parcels make up 37% of this corridor.

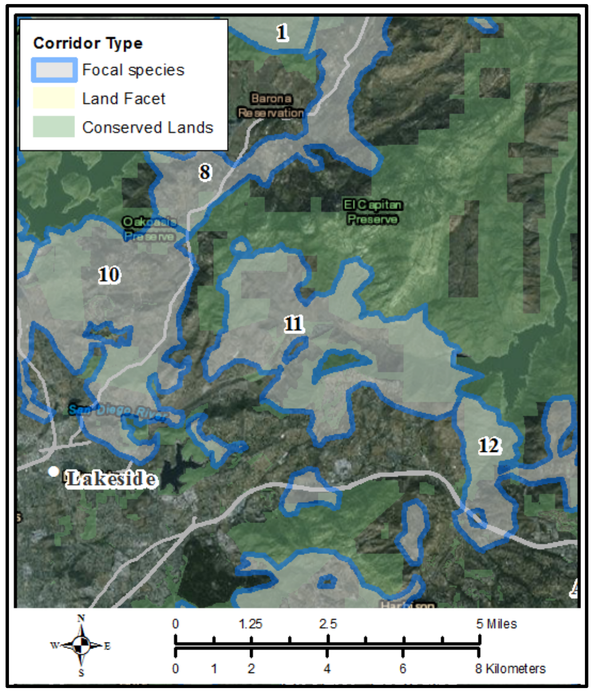
Corridor 11

4,648 acres

50% conserved

36% PAMA

Average connectivity value: 81



Corridor 11 is in the southeastern section of the study area and provides connections from the El Capitan Reservoir with El Capitan County Preserve and the Cleveland National Forest to the northwest. This corridor has mostly diffuse flow, though flow does begin to get more concentrated in the southeast near the reservoir.

Ninety-one percent of this corridor is comprised of natural land cover types and three of the five endangered species assessed are present here. Land cover types with good connectivity across Corridor 11 include chaparral, coastal sage scrub, and riparian. Developable parcels make up 21% of this corridor.

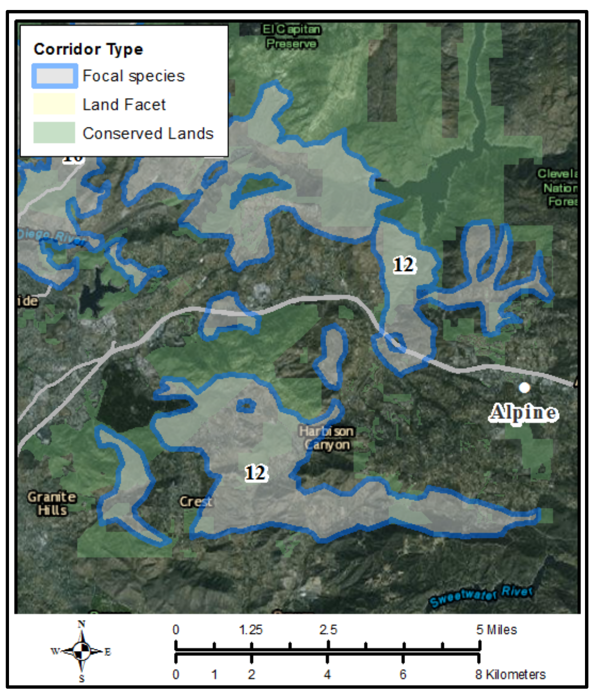
Corridor 12

7,332 acres

32% conserved

14% PAMA

Average connectivity value: 69



Corridor 12 is a collection of smaller connections in the very southeastern part of the study area. It contains and connects the Cleveland National Forest and El Capitan County Preserve to the north of Interstate 8 with Crestridge Ecological Reserve, Crest, and Crest-

Worley Preserves south of the interstate. Flow is restricted or highly channelized through most of this corridor and it is primarily comprised of the outer connectivity isopleth (top 20-30% of connectivity values). Corridor 12 has two important wildlife road crossing locations on I-8, one of which is the Chocolate Creek crossing.

Eighty-two percent of this corridor is comprised of natural land cover types and two of the five endangered species assessed are present here. Land cover types with good connectivity across this corridor include chaparral, coastal sage scrub, and riparian. Developable parcels make up 4% of this corridor.

Corridor 13

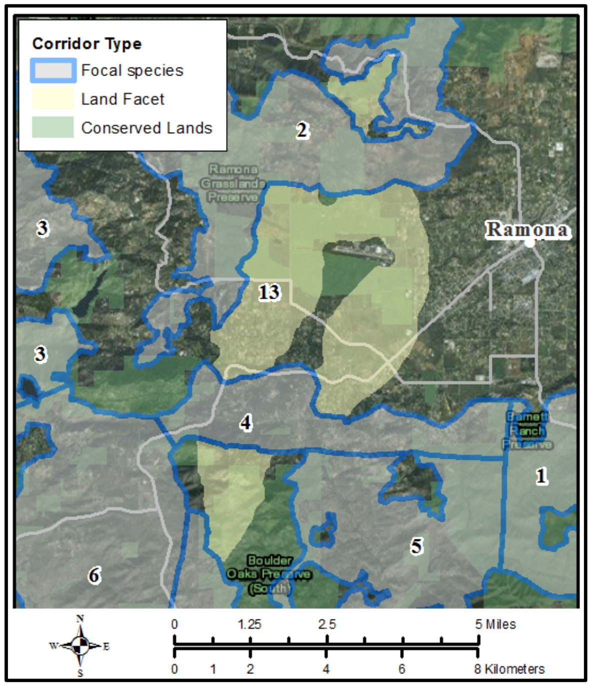
9,958 acres

34% conserved

3% PAMA

31% Draft PAMA

Average connectivity value: 42



Corridor 13, the land facet corridor, connects Cleveland National Forest lands in the north with Iron Mountain in the south through much of the Ramona Grasslands Preserve. This corridor contains one important wildlife road crossing on SR-67.

Seventy-five percent of this corridor is comprised of natural land cover types and three of the five endangered species are present here. Land cover types with good connectivity across this corridor include chaparral, coastal sage scrub, and grassland. Developable parcels make up 31% of this corridor.

Table A1. Corridor metadata table. This table displays the metric calculated for various attributes for each of the 13 corridors as well as the minimum and maximum value for each metric and the corresponding field abbreviation for the corridor shapefile product.

Category	Type	Variable / Metric	Shapefile field abbreviation	Min Value	Max Value
		Corridor ID number	Id	1	13
		Corridor Type, species–specific or land facet	C_Type		
		Corridor area in acres	Area_Ac	3,142	27,849
Conservation/Management	Conservation Status	Percent of corridor area with conserved status	Pct_Cnsvd	15	56
Conservation/Management	Conservation Status	Acres of corridor conserved	Ac_Cnsvd	479	6,874
Conservation/Management	Conservation Status	Acres of corridor unconserved	Ac_UNCnsvd	2,320	20,974
Conservation/Management	Conservation Status	Acres of corridor in PAMA	Ac_PAMA	0	1670
Conservation/Management	Conservation Status	Percent of corridor area in PAMA	Pct_PAMA	0	36
Conservation/Management	Conservation Status	Acres of corridor in with draft PAMA status	Ac_D_PAMA	0	2,597
Conservation/Management	Conservation Status	Percent of corridor area with draft PAMA status	Pct_DPAMA	0	32
Conservation/Management	Future Land Use	developable parcels	No_Dev_Pcl	10	330
Conservation/Management	Future Land Use	Number of parcels with developable land	Ac_Dev_Pcl	267	3,904
Conservation/Management	Future Land Use	Percent of corridor area with developable land	Pct_Dev_Pc	4	41
Conservation/Management	Future Land Use	Average probability of development	ProbDev_Av	0.001	0.043
Conservation/Management	Future Land Use	Minimum probability of development	ProbDev_Mn	0	0.002
Conservation/Management	Future Land Use	Maximum probability of development	ProbDev_Mx	0.004	0.327
Conservation/Management	Future Land Use	Area weighted mean average cost of developable land	priceAWM	$51,081	$984,126
Conservation/Management	Future Land Use	Area weighted sum of cost of developable land	priceAWS	$595,710	$113,979,498
Conservation/Management	Cultural	Number of recorded cultural sites in corridor	Csites	31	402
Biological Variables	Connectivity	Average value in corridor of the multi-species connectivity surface	All_spp_Val	68.6	89.9
Biological Variables	Resilience	Mean climate change resiliency value	Resilience	0.103	0.287
Biological Variables	Resilience	Proportion of corridor covered by Land Facet 1	Prop_LF1	0	71
Biological Variables	Resilience	Proportion of corridor covered by Land Facet 2	Prop_LF2	4	100
Biological Variables	Resilience	Proportion of corridor covered by Land Facet 3	Prop_LF3	0	91

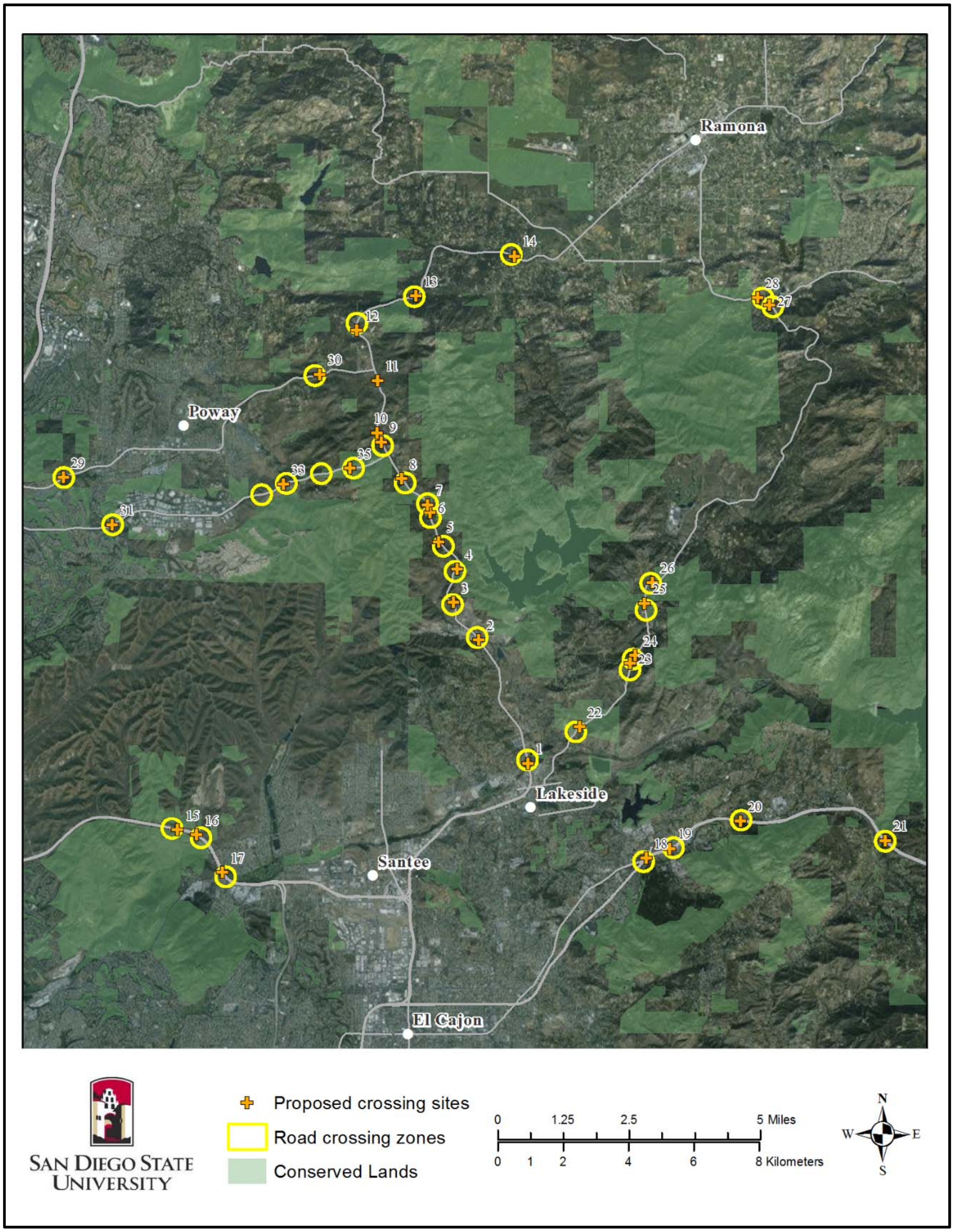
Category	Type	Variable / Metric	Shapefile field abbreviation	Min Value	Max Value
Biological Variables	Resilience	Proportion of corridor covered by Land Facet 4	Prop_LF4	0	95
Biological Variables	Focal Species Corridor	Proportion of the corridor covered by the puma-only corridor	Puma_Corr	2	100
Biological Variables	Focal Species Connectivity	Average value in corridor of the connectivity surface for puma	Puma_Val	33.4	95.3
Biological Variables	Focal Species Corridor	Proportion of the corridor covered by the bobcat-only corridor	Bcat_Corr	43	100
Biological Variables	Focal Species Connectivity	Average value in corridor of the connectivity surface for bobcat	Bobcat_Val	44.6	89.2
Biological Variables	Focal Species Corridor	Proportion of the corridor covered by the deer-only corridor	Deer_Corr	33	100
Biological Variables	Focal Species Connectivity	Average value in corridor of the connectivity surface for deer	Deer_Val	42	91.2
Biological Variables	Focal Species Corridor	Proportion of the corridor covered by the woodrat-only corridor	Wrat_Corr	73	97
Biological Variables	Focal Species Connectivity	Average value in corridor of the connectivity surface for woodrat	Wrat_Val	53.3	84.6
Biological Variables	Focal Species Corridor	Proportion of the corridor covered by the wrentit-only corridor	Wrtit_Corr	26	100
Biological Variables	Focal Species Connectivity	Average value in corridor of the connectivity surface for wrentit	Wrtit_Val	47.5	84
Biological Variables	Focal Species Corridor	Proportion of the corridor covered by the CA mouse-only corridor	Mouse_Corr	67	91
Biological Variables	Focal Species Connectivity	Average value in corridor of the connectivity surface for CA mouse	Mouse_Val	56.8	79.5
Biological Variables	T&E Species	Number of Arroyo toad occurrence points in corridor	ARTO_pts	0	149
Biological Variables	T&E Species	Proportion of Arroyo toad points in corridor out of total in study area	ARTOpropts	0	0.47
Biological Variables	T&E Species	Number of Cactus wren occurrence points in corridor	CACW_pts	0	7
Biological Variables	T&E Species	Proportion of cactus wren points in corridor out of total in study area	CACWpropts	0	0.048
Biological Variables	T&E Species	Mean habitat suitability value in corridor for Cactus wren	CACWMN	0.028	0.435
Biological Variables	T&E Species	Number of CA gnatcatcher occurrence points in corridor	CAGN_pts	0	181
Biological Variables	T&E Species	Proportion of California gnatcatcher points in corridor out of total in study area	CAGNpropts	0	0.17
Biological Variables	T&E Species	Mean habitat suitability value in corridor for California gnatcatcher	CAGNMN	0.017	0.463

Category	Type	Variable / Metric	Shapefile field abbreviation	Min Value	Max Value
Biological Variables	T&E Species	Number of Quino checkerspot butterfly occurrence points in corridor	QUCH_pts	0	6
Biological Variables	T&E Species	Proportion of Quino checkerspot butterfly points in corridor out of total in study area	QUCHpropts	0	0.286
Biological Variables	T&E Species	Mean habitat suitability value in corridor for Quino checkerspot butterfly	QUCHMN	0.088	0.362
Biological Variables	T&E Species	Number of Stephens' kangaroo rat occurrence points in corridor	SKR_pts	0	10
Biological Variables	T&E Species	Proportion of Stephens' kangaroo rat points in corridor out of total number	SKRpropts	0	0.059
Biological Variables	Species Representation	Number of Hermes copper butterfly occurrence points in corridor	HECO_pts	0	343
Biological Variables	Species Representation	Proportion of Hermes copper butterfly points in corridor out of total in study area	HECOpropts	0	0.762
Biological Variables	Species Representation	Number of coachwhip occurrence points in corridor	MAFL_pts	0	5
Biological Variables	Species Representation	Proportion of coachwhip points in corridor out of total in study area	MAFLpropts	0	0.091
Biological Variables	Species Representation	Number of granite spiny lizard occurrence points in corridor	SCOR_pts	0	10
Biological Variables	Species Representation	Proportion of granite spiny lizard points in corridor out of total number	SCORpropts	0	0.097
Biological Variables	Species Representation	Number of two-striped garter snake occurrence points in corridor	THHA_pts	0	6
Biological Variables	Species Representation	Proportion of two-striped garter snake points in corridor out of total	THHApropts	0	0.075
Biological Variables	Species Representation	Number of W. whiptail occurrence points in corridor	ASTI_pts	0	16
Biological Variables	Species Representation	Proportion of W. whiptail points in corridor out of total in study area	ASTIpropts	0	0.246
Biological Variables	Species Representation	Number of western toad occurrence points in corridor	ANBO_pts	0	151
Biological Variables	Species Representation	Proportion of western toad points in corridor out of total in study area	ANBOpropts	0	0.351
Biological Variables	Species Representation	Mean habitat suitability value in corridor for Bell's sparrow	SASPMN	0.61	0.738
Biological Variables	Species Representation	Mean habitat suitability value in corridor for California thrasher	CATHMN	0.425	0.631
Biological Variables	Species Representation	Mean habitat suitability value in corridor for Costa's hummingbird	COHUMN	0.471	0.688
Biological Variables	Species Representation	Number of pallid bat occurrence points in corridor	ANPA_pts	0	4

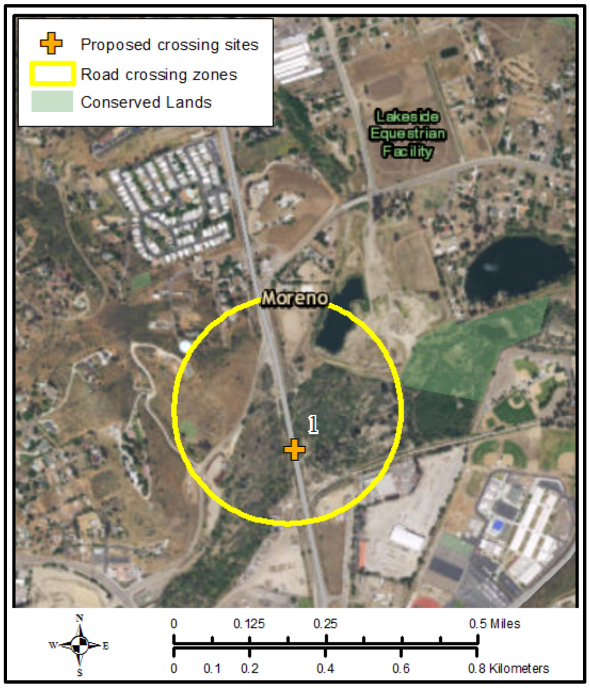
Category	Type	Variable / Metric	Shapefile field abbreviation	Min Value	Max Value
Biological Variables	Species Representation	Proportion of pallid bat points in corridor out of total in study area	ANPApropts	0.02	0.11
Biological Variables	Species Representation	Number of Townsend's big-eared bat occurrence points in corridor	COTO_pts	0	4
Biological Variables	Species Representation	Proportion of Townsend's big-eared bat points in corridor out of total	COTOpropts	0	0.308
Biological Variables	Species Representation	Number of American badger occurrence points in corridor	TATA_pts	0	2
Biological Variables	Species Representation	Proportion of American badger points in corridor out of total in study area	TATApropts	0	0.2
Biological Variables	Species Representation	Number of ringtail occurrence points in corridor	BAAS_pts	0	4
Biological Variables	Species Representation	Proportion of ringtail points in corridor out of total in study area	BAASpropts	0	0.364
Biological Variables	Vegetation	Vegetation types connected in corridor	Veg_connec	qualitative	
Biological Variables	Vegetation	Percent of corridor comprised of chaparral	PLAND_CHP	10.491	71.621
Biological Variables	Vegetation	Degree to which chaparral is aggregated in the corridor	CLUMPY_CHP	0.752	0.893
Biological Variables	Vegetation	Index of travel distance through chaparral in the corridor	GYRATE_CHP	322.921	2,850.39
Biological Variables	Vegetation	Percent of corridor comprised of coastal scrub	PLAND_CSC	1.694	49.27
Biological Variables	Vegetation	Degree to which coastal scrub is aggregated in the corridor	CLUMPY_CSC	0.717	0.89
Biological Variables	Vegetation	Index of travel distance through coastal scrub in the corridor	GYRATE_CSC	90.654	1,652.09
Biological Variables	Vegetation	Percent of corridor comprised of grassland	PLAND_GRS	1.052	7.803
Biological Variables	Vegetation	Degree to which grassland is aggregated in the corridor	CLUMPY_GRS	0.672	0.835
Biological Variables	Vegetation	Index of travel distance through grassland in the corridor	GYRATE_GRS	92.23	277.159
Biological Variables	Vegetation	Percent of corridor comprised of riparian	PLAND_RIP	0.648	7.223
Biological Variables	Vegetation	Degree to which riparian is aggregated in the corridor	CLUMPY_RIP	0.502	0.742
Biological Variables	Vegetation	Index of travel distance through riparian in the corridor	GYRATE_RIP	129.12	777.73
Biological Variables	Vegetation	Percent of corridor comprised of woodland	PLAND_WDL	0.754	16.61
Biological Variables	Vegetation	Degree to which woodland is aggregated in the corridor	CLUMPY_WDL	0.617	0.773
Biological Variables	Vegetation	Index of travel distance through woodland in the corridor	GYRATE_WDL	59.69	408.75
Threats and Stressors	Development	Percent of the corridor that has been developed	PCT_DEV	4.54	19.59

Category	Type	Variable / Metric	Shapefile field abbreviation	Min Value	Max Value
Threats and Stressors	Fragmentation	Mean intactness value in the corridor	Intactness	-0.277	0.408
Threats and Stressors	Fragmentation	Amount of corridor that is comprised of core area	EI_Ratio	18	73
Threats and Stressors	Roads	Average road density in the corridor	Road_Dens	2.597	6.285
Threats and Stressors	Fragmentation	Percent of corridor comprised of natural cover types	PLND_NAT	80	96
Threats and Stressors	Fragmentation	Degree to which natural areas are aggregated in the corridor	CLUMPY_NAT	0.5	0.77
Threats and Stressors	Fragmentation	Index of travel distance through natural areas in the corridor	GYRATE_NAT	1,572	4,046
Threats and Stressors	Disturbance	Percent of corridor comprised of sparse vegetation	PLAND_SPS	4.54	19.59
Threats and Stressors	Disturbance	Degree to which sparse vegetation is aggregated in the corridor	CLUMPY_SPS	0.712	0.828
Threats and Stressors	Disturbance	Index of travel distance through sparse vegetation in the corridor	GYRATE_SPS	127.38	1,013.83
Threats and Stressors	Fire	Frequency of departure from the mean fire return interval	FRIDMN	-54.94	-33.56
Threats and Stressors	Fire	Frequency of departure from the minimum fire return interval	FRIDMIN	-84.2	-67.1
Threats and Stressors	Fire	Frequency of departure from the maximum fire return interval	FRIDMAX	43.1	71.8
Threats and Stressors	Fire	Proportion of corridor in a low fire threat category	ThreatV0	0.021	0.209
Threats and Stressors	Fire	Proportion of corridor in a moderate fire threat category	ThreatV1	0.011	0.166
Threats and Stressors	Fire	Proportion of corridor in a high fire threat category	ThreatV2	0.012	0.537
Threats and Stressors	Fire	Proportion of corridor in a very high fire threat category	ThreatV3	0.096	0.879
Threats and Stressors	Fire	Proportion of corridor in an extreme fire threat category	ThreatV4		0.347

APPENDIX B: SR-67 WILDLIFE CROSSING STRUCTURE MAPS, DESCRIPTIONS, AND INFRASTRUCTURE RECOMMENDATIONS



Crossing Site 1

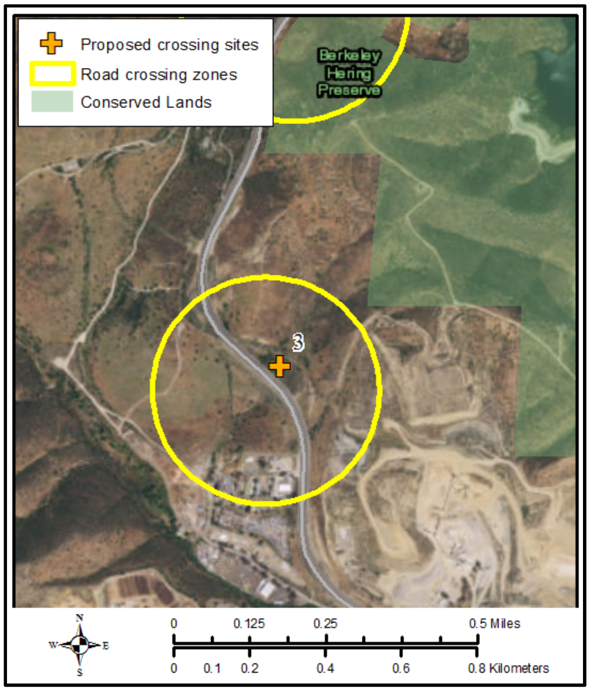


Crossing site 1 is located at the bridge over the San Diego River at Post Mile R5.95. The land on either side of the road in this location is in private ownership. The site is of high importance to wildlife and would only require minor improvements for enhancing wildlife movement. The overall size of the structure is appropriate but fencing is recommended on either side of the road running perpendicular to the bridge to prevent wildlife from accessing the industrial development in the surrounding area. Removal of the non-native vegetation in the San Diego River channel will also enhance wildlife movement through this structure.

Crossing Site 2

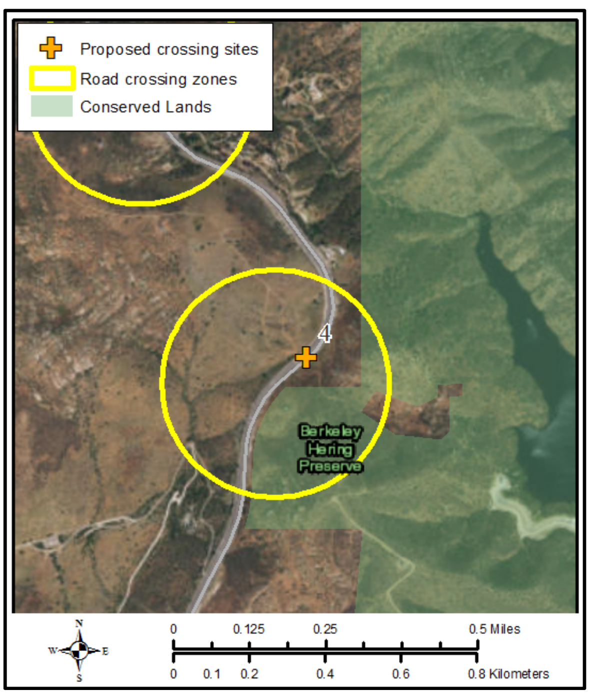
Crossing site 2 is located just south of Vigilante Road in Lakeside at Post Mile 9.05. It is of moderate importance to wildlife because there is limited suitable habitat for wildlife movement in the surrounding industrial development despite the proximity to conserved lands. The existing culvert is 7 feet in diameter and although the optimal design for wildlife would be an arched or box culvert 13.1 feet wide by 9.8 feet high, adequate wildlife movement could be achieved through minor improvements without increasing the size of the culvert. Removal of the non-native vegetation and clearing built up sediment that blocks the culvert would enhance wildlife movement through this structure. Revegetation of the dirt span leading to the culvert on the east side of the road to connect to existing vegetation should also be prioritized. On both sides of the road, 8-10 foot high fencing should also be used to reinforce wildlife movement through the existing culvert.

Crossing Site 3



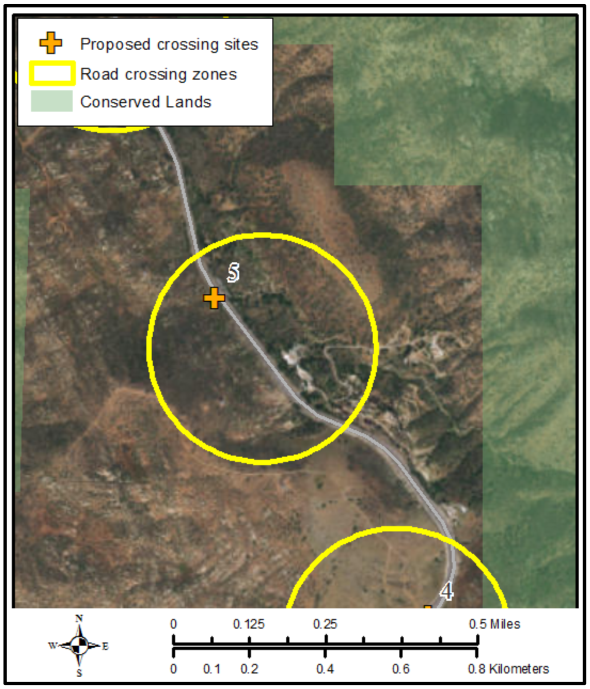
Crossing site 3 is located mid-slope on the grade leading out of Lakeside north of Vigilante Road at Post Mile 9.96. It is of extremely high importance to wildlife as it connects areas of suitable habitat and is adjacent to a large area of conserved land to the east. However, this section of road has experienced moderate levels of wildlife vehicle collisions. The existing culvert is long, narrow and set far back from the road, so will either need a major redesign or dual siting of a wildlife structure to accommodate wildlife movement. The optimal design for this site would be an arched or box culvert 26.2 feet wide by 14.8 feet high. However, the minimum recommendation for this site is 19.7 feet wide by 13.1 feet high. On both sides of the road, 8-10 foot high fencing should also be used to reinforce wildlife movement through the existing culvert.

Crossing Site 4



Crossing site 4 is near the top of the grade north of Lakeside at Post Mile 10.76. It is of high importance to wildlife to connect nearby preserved lands to the east. The existing culvert at this location is only 1.5 feet in diameter, so a major redesign is necessary to facilitate wildlife movement. The optimal design for this site would be an arched or box culvert 16.5 feet wide by 9.8 feet high. However, the minimum recommendation for this site is 13.1 feet wide by 6.6 feet high. On both sides of the road, 8-10 foot high fencing should also be used to reinforce wildlife movement through the existing culvert.

Crossing Site 5



Crossing site 5 is at the top of the grade north of Lakeside at Post Mile 11.46. It is of moderate importance to wildlife to connect nearby preserved lands. The existing culvert at this location is 3.0 feet in diameter, and will require a major redesign to facilitate wildlife movement. Because this crossing will primarily serve small animals, the optimal design is a pipe culvert 6.6 feet in diameter. However, the minimum recommendation for this site is a 3.3 foot diameter culvert. On both sides of the road, 3.5 foot high fencing with an impenetrable bottom should also be used to reinforce wildlife movement through the existing culvert.

Crossing Site 6

Crossing site 6 is located immediately south of Foster's Truck Trail at Post Mile 12.05. It is of extremely high importance to wildlife as it connects areas of suitable habitat and is one of the few locations on the road where there are conserved lands on either side of the road. Although the existing culvert is large, with a diameter of 7.5 feet, it should be larger and more open to accommodate movement, particularly of larger species. The optimal design for this site would be an arched or box culvert 26.2 feet wide by 14.8 feet high. However, the minimum recommendation for this site is 19.7 feet wide by 13.1 feet high. On both sides of the road, 8-10 foot high fencing should also be used to reinforce wildlife movement through the existing culvert.

Crossing Site 7

Crossing site 7 is located just north of Foster's Truck Trail at Post Mile 12.25. It is of high importance to wildlife as it connects areas of suitable habitat and is one of the few locations on the road where there are conserved lands on either side of the road. However, the siting and approach to this culvert make it less attractive for wildlife movement than the site for Crossing 6. The existing culvert is 7.5 feet in diameter and although the optimal design for wildlife would be an arched or box culvert 13.1 feet wide by 9.8 feet high, adequate wildlife movement could be achieved through minor improvements without increasing the size of the culvert. Removal of the non-native vegetation and clearing built up sediment that blocks the culvert would enhance wildlife movement through this structure. On both sides of the road, 8-10 foot high fencing should also be used to reinforce wildlife movement through the existing culvert.

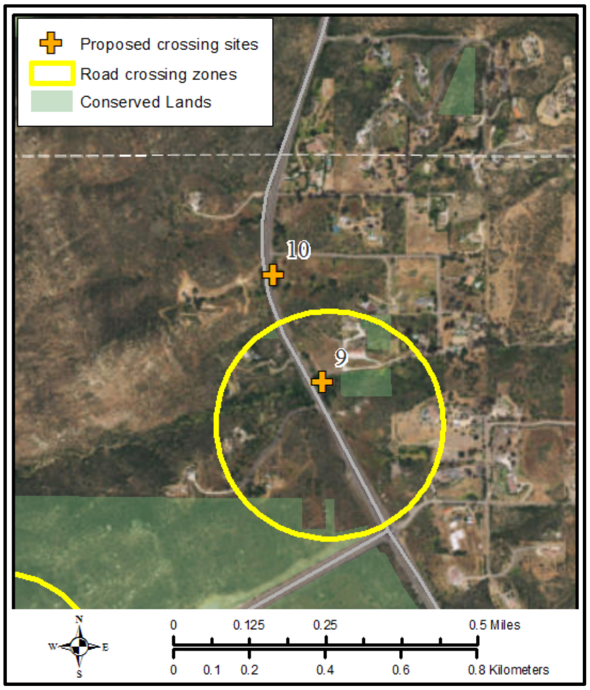
Crossing Site 8

Crossing site 8 is located just north of Lazy Acres Drive at Post Mile 12.95. It is of moderate importance to wildlife as there is scattered housing through the area, which is dominated by non-native vegetation. There are adjacent conserved lands nearby, but they are not contiguous across the roadway. The existing culvert on site is 3.0 feet in diameter, and although the optimal crossing design would be an arched or box culvert 13.1 feet wide by 6.6 feet high, a pipe culvert 6.6 feet in diameter would still provide for adequate wildlife movement. Although this is a change in size from the current structure, we have identified it as a minor improvement because this retrofit could occur during normal culvert replacement. Removal of the non-native vegetation and addressing erosion and gullying leading to the culvert would enhance wildlife movement through this structure. On both sides of the road, 8-10 foot high fencing should also be used to reinforce wildlife movement through the structure.

Crossing Site 9

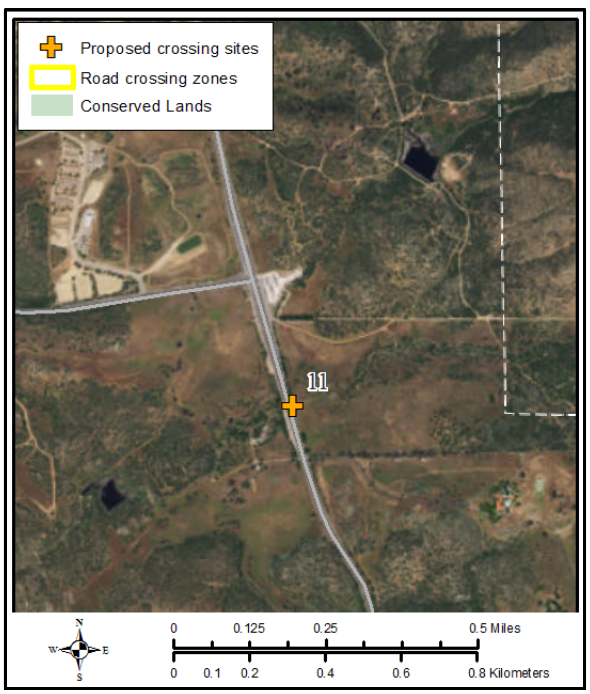
Crossing site 9 is located in the riparian zone that crosses SR-67 north of Scripps Poway Parkway at Post Mile 13.75. It is of extremely high importance to wildlife as it connects areas of suitable habitat and experiences moderate levels of wildlife vehicle collisions. The existing culvert is large at 5.5 feet in diameter, but major improvements are necessary to enhance wildlife movement across the road in this location. The optimal design for this site would be an arched or box culvert 26.2 feet wide by 14.8 feet high. However, the minimum recommendation for this site is 16.4 feet wide by 9.8 feet high. If hydrologic issues preclude optimal wildlife design, dual siting of structures for drainage and wildlife are recommended. On both sides of the road, 6-8 foot high fencing should also be used to reinforce wildlife movement through the existing culvert.

Crossing Site 10



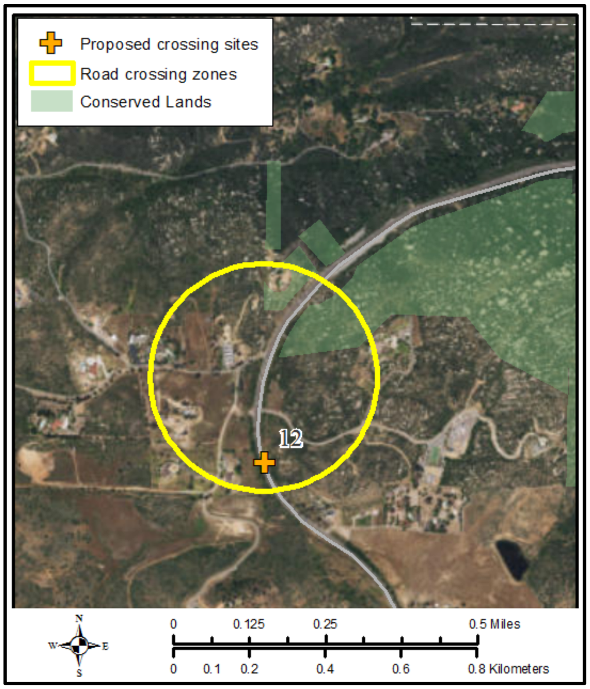
Crossing site 10 is located north of Scripps Poway Parkway at Post Mile 13.9. Although it was not identified by our modeling approach, it is of high importance to wildlife as it connects areas of suitable habitat and past monitoring has documented multiple species crossing the road at this location (Jennings and Lewison 2015). The existing culvert is 7.0 feet in diameter and although the optimal design for wildlife would be an arched or box culvert 13.1 feet wide by 9.8 feet high, adequate wildlife movement could be achieved through minor improvements without increasing the size of the culvert. Removal of the non-native vegetation and clearing built up sediment that blocks the culvert would enhance wildlife movement through this structure. On both sides of the road, 8-10 foot high fencing should also be used to reinforce wildlife movement through the existing culvert.

Crossing Site 11



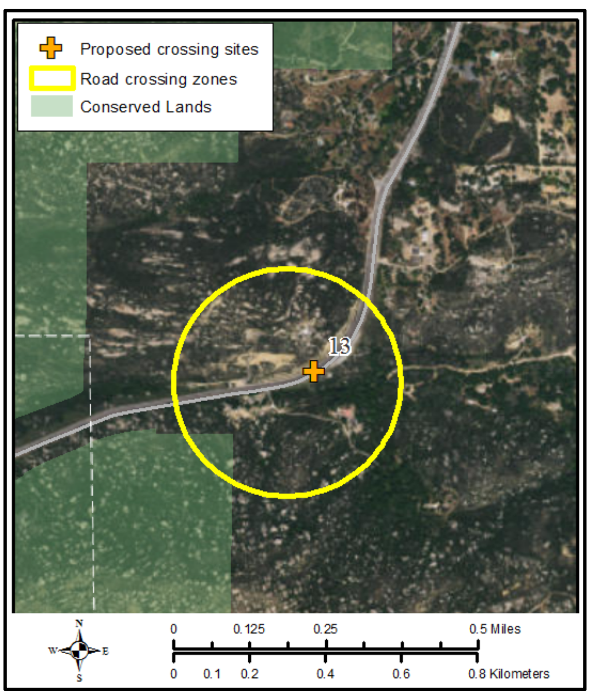
Crossing site 11 is located south of Poway Road at Post Mile 14.98. Although it was not identified by our modeling approach, it is of high importance to wildlife as it connects areas of suitable habitat and has been documented in past monitoring (Jennings and Lewison 2015) as accommodating multiple species crossing the road. The existing culvert is 8.5 feet in diameter and although the optimal design for wildlife would be an arched or box culvert 13.1 feet wide by 9.8 feet high, adequate wildlife movement could be achieved through minor improvements without increasing the size of the culvert. Enhancing native vegetation leading to the structure on the east side and clearing built up sediment that blocks the culvert would enhance wildlife movement through this structure. On both sides of the road, 8-10 foot high fencing should also be used to reinforce wildlife movement through the existing culvert.

Crossing Site 12



Crossing site 12 is south of Chaparral Way on a curve leading toward Mount Woodson at Post Mile 16.05. It is of high importance to wildlife as it connects areas of suitable habitat and is adjacent to conserved lands. The existing culvert at this location is only 3.0 feet in diameter, so a major redesign is necessary to facilitate wildlife movement. The limited grade relief at this site will require additional work to accommodate a larger structure. The optimal design for this site would be an arched or box culvert 13.1 feet wide by 6.6 feet high. However, the minimum recommendation for this site is a 6.6-foot diameter culvert. On both sides of the road, 6-8 foot high fencing should also be used to reinforce wildlife movement through the existing culvert.

Crossing Site 13



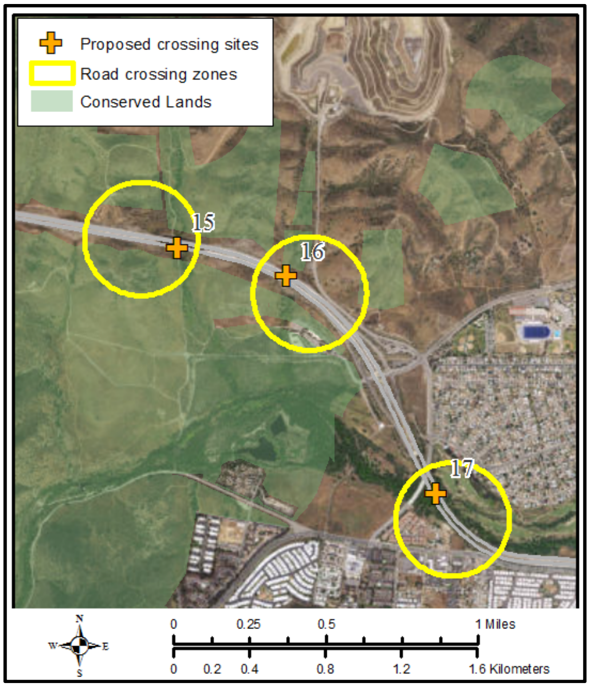
Crossing site 13 is located at the top of the Mount Woodson grade at Post Mile 17.61. It is of extremely high importance to wildlife as it connects areas of unique suitable habitat, conserved lands, and has experienced high levels of wildlife vehicle collisions. There is no existing structure providing for wildlife movement in this area, so it will require a major improvement to construct a suitable wildlife crossing structure. Based on topography and movement patterns of focal species for this crossing structure, a wildlife overpass is the optimal design for this site. The overpass should be between 164 and 230 feet wide and will need to connect in an area where wildlife will be likely to approach the overpass. The structure should also be appropriately vegetated to encourage wildlife to approach and use the structure for crossing the highway. On both sides of the road, 8-10 foot high fencing should also be used to reinforce wildlife movement through the existing culvert.

Crossing Site 14

Crossing site 14 is between Via Penasco and Rancho de Oro Drive at Post Mile 20.17. It is of moderate importance to wildlife as it connects areas of suitable habitat but there are no conserved lands in the vicinity. The existing culvert at this location is only 3.0 feet in diameter, so a major redesign is necessary to facilitate wildlife movement. The limited grade relief at this site will require additional work to accommodate a larger structure. The optimal design for this site would be an arched or box culvert 13.1 feet wide by 6.6 feet high. However, the minimum recommendation for this site is a 6.6-foot diameter culvert. Fencing should be considered for this site, but there are few places to anchor fence ends and there are a number of driveways in the area that could limit fence functionality.

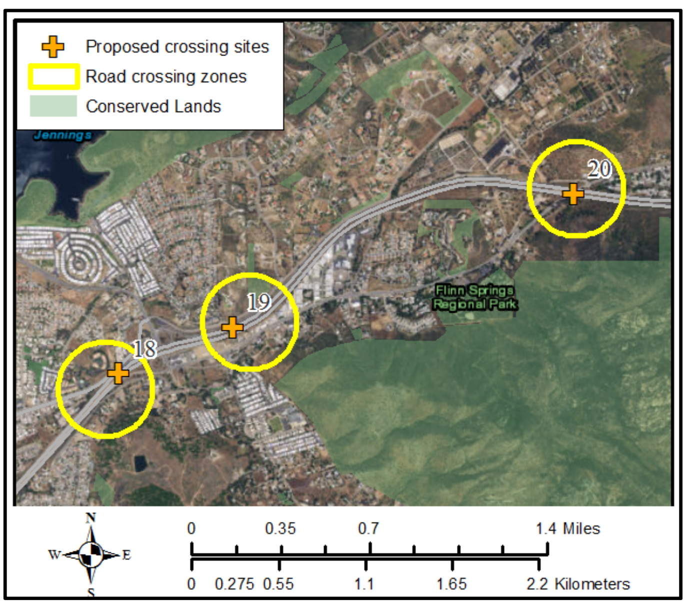
Additional Crossing Structures

<u>SR-52 Crossings</u>

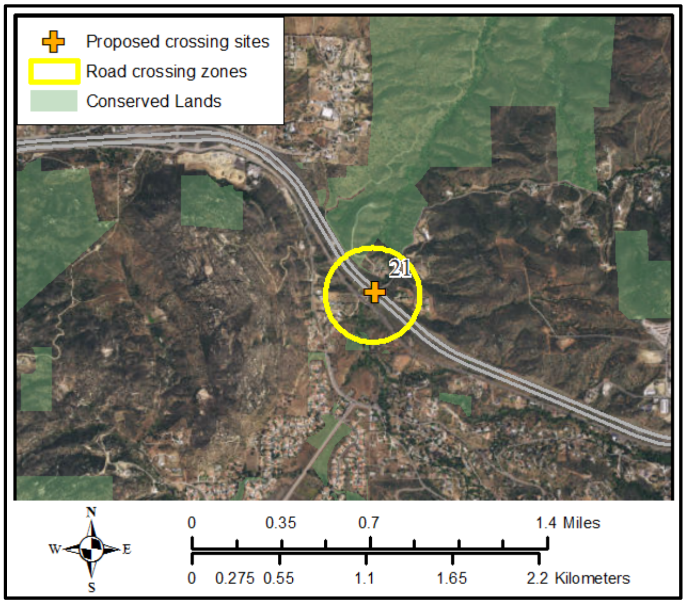


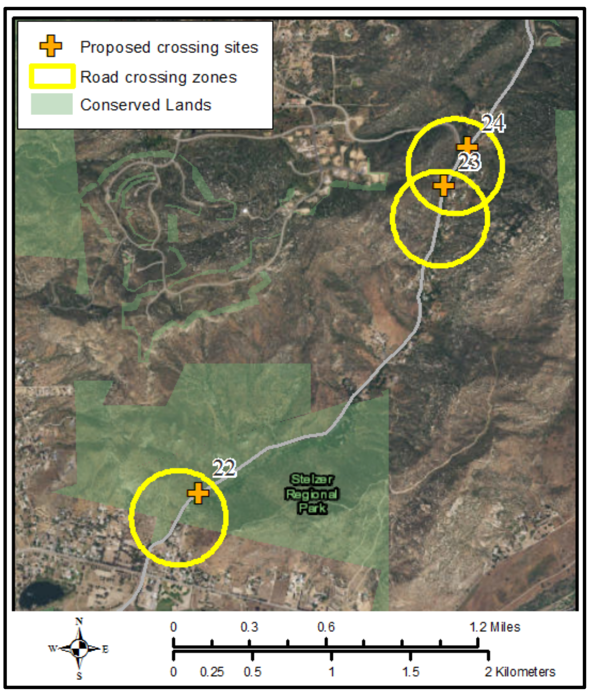
There are three sites along SR-52 that are important wildlife crossing areas: Post Miles 12.44, 12.64, and 13.72. This area is one of the primary connections for wildlife moving in and out of Mission Trails Regional Park. All three only require minor improvements as they likely facilitate wildlife movement in their current design. The installation of fencing to reinforce wildlife use of the structures, as well as some clearing of non-native vegetation under one of the bridges, is likely to improve the condition of the structures for wildlife movement.

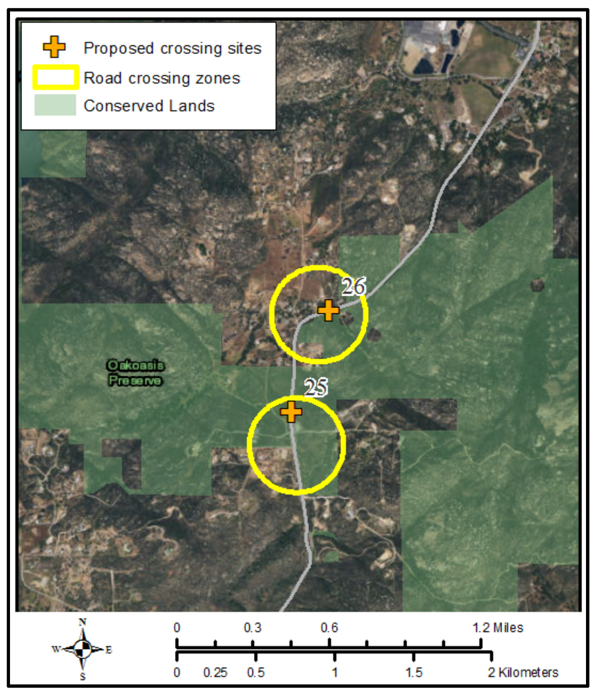
<u>I-8 Crossings</u>



There are four sites along I-8 that are important wildlife crossing areas: Post Miles 21.66, 22.13, 23.67, and 26.75. The first two are of moderate importance for wildlife movement, but the other two are of high and very high importance. As no structures exist at these sites that can accommodate wildlife movement, major improvements are necessary at all four sites. Once redesigned, the installation of fencing to reinforce wildlife use of the structures is likely to improve the condition of the structures for wildlife movement.

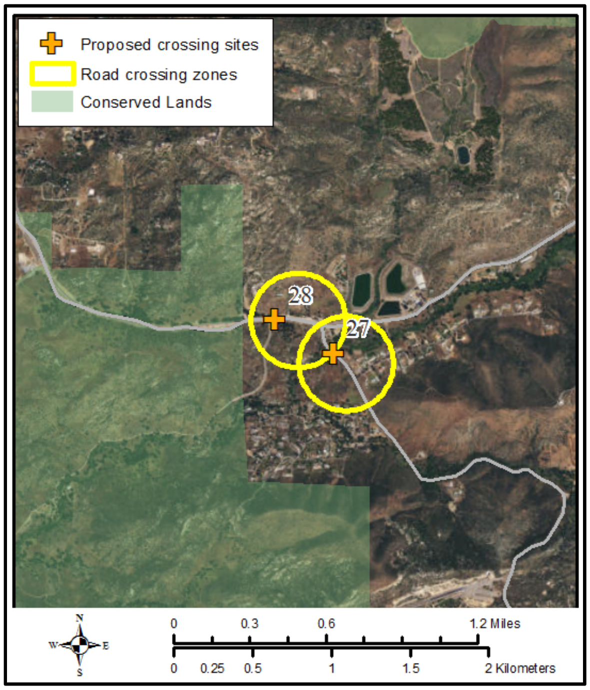




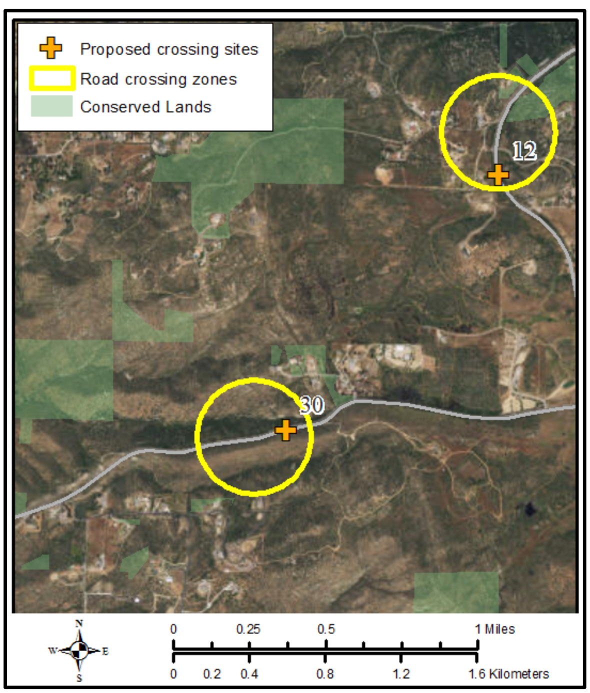


Wildcat Canyon Road Crossings

There are seven sites along Wildcat Canyon Road (with one of those being adjacent to Wildcat Canyon Road on San Vicente Road) that are important to wildlife movement. Most are of moderate or high importance to wildlife, but many require major improvements because there are not existing structures adequate to support wildlife movement. In total, four out of seven site will need major improvements. Only minor improvements are needed at the existing wildlife tunnel site. Some sediment flow and



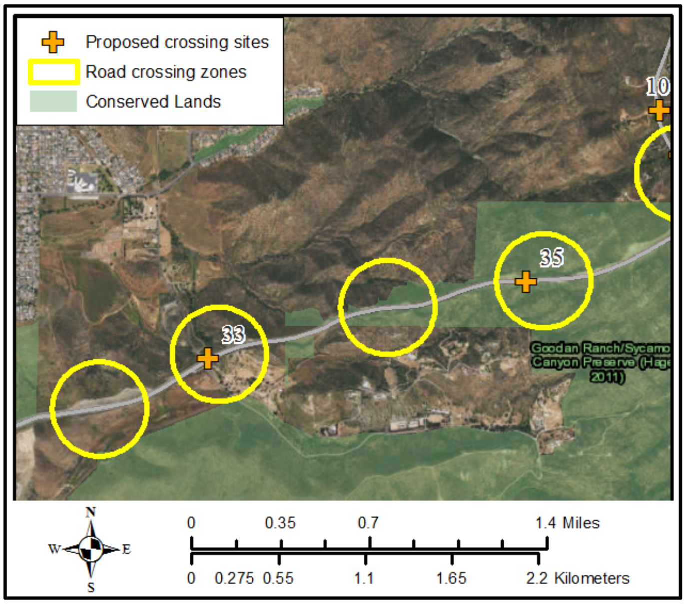
erosion control may be necessary here as well as revegetation with native species, but otherwise, this site appears functional. The installation of fencing to reinforce wildlife use of the structures, as well as some clearing of non-native vegetation under one of the bridges, is likely to improve the condition of the structures for wildlife movement.



Poway Road Crossings

There were two sites identified as having a high importance to wildlife movement on Poway Road. At one site, there is no existing structure, and a major improvement is necessary. At the other, there is an existing culvert that can accommodate the movement by small animals at that location. The installation of fencing to reinforce wildlife use of the structures is also likely to improve the condition of the structures for wildlife movement.

Scripps Poway Parkway Crossings



Although there were originally five crossing zones identified along Scripps Poway Parkway through our modeling results, there are final recommendations for only three of those sites. The remaining two had few options for siting and placement given the topography, road cut, and proximity of other proposed wildlife crossings. Two of these three sites were of high importance for wildlife movement and require major improvements to accommodate an adequate degree of wildlife movement. The third site is the location of the Scripps Poway Parkway wildlife tunnel that is functional but could benefit from fence extension and improvement.

Table B1. Detailed wildlife crossing recommendations for SR-67

Id	Post Mile	Wildlife Priority	Improve-ment Type	Nearest Crossing (mi)	Rd width (ft)	Right-of-way (ft)	Optimal Crossing Type	Minimum Crossing Type	New, Retro, or Exists	Optimal width (ft)	Optimal height (ft)	Min width (ft)	Min height (ft)	Existing diameter (ft)	In corridor	Conserved	Min fence length E or S (ft)	Min fence length N or W (ft)
1	R5.95	2	Minor	1.209	45.9	164.0	Bridge		Exists	-	13.1	-	9.8	Unknown	Y	N	-	-
2	9.05	3	Minor	0.896	114.8	141.1	Arched or box culvert	Pipe culvert	Retrofit	13.1	9.8	7.0	-	7.0	Y	N	590.6	656.2
3	9.96	1	Major	0.636	164.0	502.0	Arched or box culvert		Retrofit	26.2	14.8	19.7	13.1	4.0	Y	N	1312.3	1476.4
4	10.76	2	Major	0.629	101.7	150.9	Arched or box culvert		Retrofit	16.4	9.8	13.1	6.6	1.5	Y	N	1640.4	2460.6
5	11.46	3	Major	0.588	144.4	150.9	Pipe culvert		Retrofit	6.6	-	3.3	-	3.0	Y	N	820.2	328.1
6	12.05	1	Major	0.151	131.2	150.9	Arched or box culvert		Retrofit	26.2	14.8	19.7	13.1	7.5	Y	N	984.3	1312.3
7	12.25	2	Minor	0.151	85.3	157.5	Arched or box culvert	Pipe culvert	Retrofit	13.1	9.8	7.5	-	7.5	Y	N	1312.3	2624.7
8	12.95	3	Minor	0.696	88.6	141.1	Arched or box culvert	Pipe culvert	Retrofit	13.1	6.6	6.6	-	3.0	Y	N	771.0	1082.7
9	13.75	1	Major	0.194	170.6	160.8	Arched or box culvert		Retrofit	26.2	14.8	16.4	9.8	5.5	Y	N	1148.3	820.2
10	13.9	2	Minor	0.194	55.8	150.9	Arched or box culvert	Pipe culvert	Retrofit	13.1	9.8	7.0	-	7.0	Y	N	1394.4	820.2
11	14.98	2	Minor	0.996	55.8	150.9	Arched or box culvert	Pipe culvert	Retrofit	13.1	9.8	8.5	-	8.5	Y	N	1378.0	2296.6
12	16.05	2	Major	1.034	82.0	150.9	Arched or box culvert	Pipe culvert	Retrofit	13.1	6.6	6.6	-	3.0	Y	N	1804.5	1804.5
13	17.61	1	Major	1.311	114.8	311.7	Wildlife overpass		New	229.7	-	164.0	-	-	Y	N	-	-
14	20.17	3	Major	2.016	82.0	114.8	Arched or box culvert	Pipe culvert	Retrofit	13.1	6.6	6.6		3.0	Y	N	-	-

Id	Post Mile	Fence specifics	Design features	Near-term Recommendation	Aerial connectivity considerations	Notes
1	R5.95	Site visit needed to determine if fencing to direct wildlife under bridge is necessary	Clear some vegetation to ensure clear path and line of sight. Remove invasives	Clear some vegetation to ensure clear path and line of sight. Remove invasives	Directional structure to encourage flight behavior higher than traffic	Fencing perpendicular to road may be possible within Caltrans right-of-way but would need adjacent land owners to agree
2	9.05	8-10 ft high, impenetrable bottom, fine mesh	Enhance vegetative strip on east side of road - expand to crossing structure. Improve water drainage in low area of crossing. Control erosion off of industrial development areas on the E side of highway	Clear sediment and debris in southern-most structure to increase height on east side (currently partially obstructed). Control invasives surrounding crossings, especially on west side. Restore native vegetation on both sides of highway	Directional structure to encourage flight behavior higher than traffic. Need to improve vegetative structure/height on east side to support aerial crossings	
3	9.96	8-10 ft high, impenetrable bottom, fine mesh	Lighting inside structure, contour entrance to structure on E side to enhance line of sight through structure. This should also happen on slope on W side	Install seasonal signage and flashing lights to increase awareness about this area as a wildlife-vehicle collision hot spot and slow traffic during fall evening rush hour	Directional structure to encourage flight behavior higher than traffic - topography and natural veg support aerial crossings just north of underpass location. Need additional vegetative structure on E and W slopes to support crossings	Lighting could come from skylight/tube in median, addition of reflective paint inside structure at either end, or a light powered via a wired solar panel outside the structure.
4	10.76	8-10 ft high, impenetrable bottom, fine mesh			Directional structure to encourage flight behavior higher than traffic; Could also plant additional trees (e.g. sycamore or coast live oak) to match up canopy on E and W sides	
5	11.46	3.5 ft high, impenetrable bottom, fine mesh	Rocks, logs, and low veg near entrance and inside structure to provide low cover for small species	Clear sediment and debris	Directional structure to encourage flight behavior higher than traffic; Could plant additional trees (e.g. sycamore or coast live oak) to match up canopy on E and W sides	New structure will need to emerge at a higher elevation closer to road on east side than current structure
6	12.05	8-10 ft high, impenetrable bottom, fine mesh	Rocks, logs, and low veg near entrance and inside structure to provide low cover for small species	Straighten structure to improve line of sight. Install minor lighting inside. Clear vegetation, especially on east side to allow easier access and line of sight	Directional structure to encourage flight behavior higher than traffic	Best existing structure for deer. Potential project in the future; flagged for future repair
7	12.25	8-10 ft high, impenetrable bottom, fine mesh		Clear some vegetation from W side to enhance visibility; remove some	Directional structure to encourage flight behavior higher than traffic; Could also	

Id	Post Mile	Fence specifics	Design features	Near-term Recommendation	Aerial connectivity considerations	Notes
				sediment to increase structure height; clean up debris on both sides to enhance habitat at structure; remove invasives (e.g., pepper tree)	plant additional trees (e.g. sycamore or coast live oak) to match up canopy on E and W sides	
8	12.95	8-10 ft high, impenetrable bottom, fine mesh		Remove invasives near structure. Address erosion and gullying in drainage to structure	Directional structure to encourage flight behavior higher than traffic; Could also plant additional trees (e.g. sycamore or coast live oak) to match up canopy on E and W sides	
9	13.75	6-8 ft high; fine mesh and impenetrable bottom	Rocks and logs on inside and outside of structure for small-scale habitat			Only true riparian culvert on SR-67. Culvert in good condition and likely won't need replacement for drainage
10	13.9	8-10 ft high, impenetrable bottom, fine mesh				Metal pipe in poor shape; Caltrans will likely line
11	14.98	8-10 ft high, impenetrable bottom, fine mesh				Metal pipe in poor shape; Caltrans will likely line
12	16.05	6-8 ft high; fine mesh and impenetrable bottom	Restore native vegetation, control erosion/gullying in area		Topography may not support aerial connectivity here	
13	17.61	~800 ft on either side of roadway, 8-10 ft high			May be some connectivity for flying species if overpass is adequately vegetated	Recreational path on bridge should be physically and visually isolated from remainder of overpass
14	20.17	No good tie in. Any fencing should be fine mesh and have impenetrable bottom to funnel small animals	low cover on outside and inside of structure (rocks, logs)		Topography may not support aerial connectivity here	Location is a minor draw but topography is generally flat in this area

Table B2. Detailed wildlife crossing recommendations for other roads in the SR-67 regional study area

Id	Road	Wildlife Priority	Improvement Type	Nearest Crossing (mi)	Rd width (ft)	Right-of-way (ft)	Optimal Crossing Type	Minimum Crossing Type	New, Retro, or Exists	Optimal width (ft)	Optimal height (ft)	Min width (ft)	Min height (ft)	In corridor	Conserved	Min fence length E or S (ft)	Min fence length N or W (ft)
15	SR-52	1	Minor	0.371	820.2	508.5	Bridge		Exists		13.1		9.8	Y	Y		
16	SR-52	2	Major	0.371	180.4	511.8	Arched or box culvert	Pipe culvert	Exists	16.4	9.8	13.1	6.6	Y	Y	2460.6	984.3
17	SR-52	2	Minor	0.865	492.1	187.0	Bridge		Exists		13.1		9.8	N	N		
18	I-8	3	Major	0.487	426.5	475.7	Arched or box culvert		New	23.0	11.5	16.4	8.2	N	N	1148.3	721.8
19	I-8	3	Major	0.487	574.1	393.7	Arched or box culvert		New	23.0	11.5	16.4	8.2	N	N	2624.7	1443.6
20	I-8	2	Major	1.443	246.1	262.5	Bridge		Retrofit		13.1		9.8	Y	N		
21	I-8	1	Major	2.786	426.5	656.2	Bridge	Arched culvert	Retrofit or new addition	23.0	11.5	16.4	8.2	Y	N		
22	Wildcat Canyon	3	Major	1.209	65.6	62.3	Arched or box culvert	Pipe culvert	Retrofit	13.1	9.8	6.6		Y	Y	1410.8	754.6
23	Wildcat Canyon	3	Major	0.176	65.6	62.3	Arched or box culvert	Pipe culvert	Retrofit	13.1	9.8	6.6		Y	N	820.2	246.1
24	Wildcat Canyon	2	Major	0.176	72.2	52.5	Arched or box culvert	Pipe culvert	New	13.1	9.8	6.6		Y	N	1017.1	754.6
25	Wildcat Canyon	2	Minor	0.426	78.7	59.1	Box culvert/tunnel		Exists	16.4	13.1	13.1	9.8	Y	Y		
26	Wildcat Canyon	2	Major	0.426	39.4	65.6	Arched or box culvert	Pipe culvert	New	13.1	9.8	6.6		Y	Y	1066.3	984.3
27	Wildcat Canyon	1	Minor	0.265	44.3	147.6	Bridge		Exists		13.1		9.8	Y	N		
28	San Vicente Rd	2	Minor	0.265	59.1	105.0	Multiple arched culvert		Exists	16.4	9.8	13.1	6.6	Y	N	1378.0	1640.4
29	Poway Rd	3	Major	1.293	105.0	105.0	Arched or box culvert	Pipe culvert	New	13.1	6.6	6.6		Y	N	459.3	1082.7
30	Poway Rd	3	Minor	1.090	39.4	131.2	Pipe culvert		Retrofit	6.6		3.3		Y	N		

Id	Road	Wildlife Priority	Improvement Type	Nearest Crossing (mi)	Rd width (ft)	Right-of-way (ft)	Optimal Crossing Type	Minimum Crossing Type	New, Retro, or Exists	Optimal width (ft)	Optimal height (ft)	Min width (ft)	Min height (ft)	In corridor	Conserved	Min fence length E or S (ft)	Min fence length N or W (ft)
31	Scripps Poway Pkwy	2	Major	1.293	121.4	108.3	Arched or box culvert	Pipe culvert	New and retrofit	13.1	6.6	6.6		Y	Y	918.6	820.2
33	Scripps Poway Pkwy	2	Major	1.292	105.0	124.7	Arched or box culvert	Pipe culvert	New	16.4	9.8	13.1	8.2	Y	N	1574.8	1066.3
35	Scripps Poway Pkwy	1	Minor	0.788	105.0	534.8	Box culvert/tunnel		Exists	16.4	13.1	13.1	9.8	Y	Y		

Id	Fence specifics	Design features	Near-term Recommendation	Aerial connectivity considerations	Notes
15				May be some connectivity for flying species under bridge	Check height and condition; May need invasive control or some native habitat restoration
16	8-10 ft high, impenetrable bottom, fine mesh	Rocks, logs, and low veg near entrance and inside structure to provide low cover for small species; provide adequate native cover leading to either end of culvert		May be some connectivity for flying species	Major improvement needed because culvert outlets on south side and only extends north to median; must be extended full length of road to allow for wildlife crossings
17			Clear some vegetation to ensure clear path and line of sight. Remove invasives	May be some connectivity for flying species under bridge	Must cross both 52 and West Hills Parkway. Check height and condition under both
18	8-10 ft high, impenetrable bottom, fine mesh	Some vegetation restoration (as compatible with transmission line zone)		Ensure transmission lines have visual markers and low electrocution potential	At transmission line right-of-way
19	8-10 ft high, impenetrable bottom, fine mesh	Light tubes at intervals through median sections or install lighting in structure		Topography may not support aerial connectivity here	N side elevated above S side. May require deeper structure and site prep on N side or different structure type or angle
20	Increase fence height to 8-10 m. Current placement OK.			May be some connectivity for flying species under bridge	Crossing should be moved E to Flinn Springs bridge on Old Highway 80. Bridge length should be expanded and aprons moved back to allow for vegetated strip under bridge for wildlife movement parallel to traffic on either side. Good vegetative cover already
21	8-10 ft high, impenetrable bottom, fine mesh			May be some connectivity for flying species under bridge	Improve intersection of Peutz Valley Rd and Alpine Boulevard. Need N-S connection of canyon. On Peutz Valley Rd, native vegetation and slope parallel to road should be improved to allow for wildlife movement
22	8-10 ft high, impenetrable bottom,	low cover on outside and inside of structure (rocks, logs)		Topography and vegetation should support this naturally. May need directional structure to encourage	

Id	Fence specifics	Design features	Near-term Recommendation	Aerial connectivity considerations	Notes
	fine mesh			flight behavior higher than traffic.	
23	8-10 ft high, impenetrable bottom, fine mesh		Remove invasives	Directional structure to encourage flight behavior higher than traffic - topography and natural veg support aerial crossings here.	Perhaps a single structure just N of driveway for 12050 Wildcat Cyn Rd.
24	8-10 ft high, impenetrable bottom, fine mesh				Suggested placement - just north of Muth Valley Road
25		Potentially add internal structure elements (rocks, logs) to facilitate movement by smaller species. Consider creating a wildlife-only section of the crossing shielded from the human use area	Control erosion in surrounding area to enhance cover in vicinity of tunnel	May be some connectivity for flying species through tunnel	
26	8-10 ft high, impenetrable bottom, fine mesh	Rocks, logs, and low veg near entrance and inside structure to provide low cover for small species		Directional structure to encourage flight behavior higher than traffic - topography and natural veg support aerial crossings here.	Suggested placement - just south of Cienga Road
27				May be some connectivity for flying species under bridge	Check height and condition; May need vegetation clearing to allow line of sight for crossings of species like deer
28	Need extended fencing, 8-10 ft high; fine mesh with impenetrable bottom		Ensure revegetation with some lower cover and native shrubs is part of restoration of site after widening of San Vicente Road	Topography may not support aerial connectivity here	Double arched culvert under San Vicente Road? Current dimensions may not be suitable for deer crossings
29	8-10 ft high, impenetrable bottom,		Install seasonal signage and flashing lights to increase awareness about this area as a		Area is a narrow pinchpoint but crossing is important for connecting open spaces to allow for movement into and out of Penasquitos Creek and

Id	Fence specifics	Design features	Near-term Recommendation	Aerial connectivity considerations	Notes
	fine mesh		wildlife-vehicle collision hot spot and slow traffic during fall evening rush hour		under I-15.
30			Ensure existing culverts in this stretch are cleared of debris and have adequate energy dissipators to avoid gullying and erosion	Topography will challenge aerial connectivity here	Difficult structure placement due to elevated S side of the road and canyon on N side of the road
31	8-10 ft high, impenetrable bottom, fine mesh	Need to restore native vegetation; need dry crossing in structure that runs NW-SE to cross both Pomerado and Scripps Poway Pkwy	Clear sediment and debris in existing crossing. Create dry crossing in existing culvert, restore native vegetation, and rocks, logs, and low veg near entrance and inside structure to provide low cover for small species		Area is a narrow pinchpoint but crossing is important for connecting open spaces to allow for movement to/from Sycamore Cyn, Beeler Cyn, and Penasquitos Cyn. Need to cross both Scripps Poway Pkwy and Pomerado here
33	6-8 ft high; fine mesh and impenetrable bottom	Rocks, logs, and low veg near entrance and inside structure to provide low cover for small species			Target crossing for east side of Sycamore Canyon Road
35	Possible need to extend fencing or increase fence height. Perhaps add wing top to fence to prevent climbing	Potentially add internal structure elements (rocks, logs) to facilitate movement by smaller species. Consider creating a wildlife-only section of the crossing shielded from the human use area		May be some connectivity for flying species through tunnel	Scripps Poway Parkway Wildlife Tunnel