PLANNING FOR CONNECTIVITY UNDER CLIMATE CHANGE:

USING BOBCAT MOVEMENT TO ASSESS LANDSCAPE CONNECTIVITY ACROSS SAN DIEGO COUNTY'S OPEN SPACES

Photo Credit: Shouqin Huo

SAN DIEGO STATE UNIVERSITY

FINAL REPORT

JUNE 2013

PREPARED FOR THE SAN DIEGO FOUNDATION

GRANT NUMBER C-2011-00177

BY:

MEGAN JENNINGS

REBECCA LEWISON

TABLE OF CONTENTS

Executive Summary 5
Acknowledgements 6
Introduction 7
Methods 8
  Data Collection 8
    Study Area 8
    Remote Cameras 9
    Mortality Assessment 9
    Animal Capture and Telemetry 10
    Genetic Sampling 10
  Data Analysis 10
    Remote Cameras and Occupancy Modeling 10
    Mortality Assessment 11
    Home Range 11
    Habitat Models 11
    Genetic Assessment 12
Results 13
    Remote Cameras and Occupancy Modeling 13
    Mortality Assessment 13
    Telemetry and Home Range Analysis 14
    Habitat Models 14
    Connectivity Assessment 15
    Genetic analysis 15
Discussion 16
  Current levels of connectivity 17
    Genetics 17
    Movement data 17
    Habitat models 18
  Potential impediments to connectivity 18
    Recreation 18
    Road mortality 19
    Other mortality sources 19
    Development 19

Connectivity under climate change and land use projections ... 20

Future Directions ... 20

References ... 22

Figures and Tables ... 27

Appendix A: Habitat Modeling Methodology ... 47

Appendix B: Habitat Suitability and Connectivity Modeling Methodology ... 49

Appendix C: Occupancy Model Selection and Results ... 50

List of Figures and Tables

Figure 1. Study area map……………..………………………………………………..…………28
Figure 2. Remote camera station map………………………………………….……………...29
Figure 3. Map of bobcat occupancy rates at remote camera stations…………………………....30
Figure 4. Roadkill mortality location map……………………………………………………….31
Figure 5. GPS point location and LoCoH home range map for collared bobcats……………….32
Figure 6. LoCoH home range map for collared bobcats………………………………………....33
Figure 7. Modeled habitat suitability map under current and future conditions……………..…...34
Figure 8. Cost-weighted distance connectivity map under current and future conditions…..…...35
Figure 9. Map of genetic sampling locations…………………………………………………….36
Figure 10. Graph of mean estimated probability of the number of bobcat subpopulations….…..37
Figure 11. Map of linkage sites with assessment of current status……………….…………...38
Table 1. List of camera locations by study area, site type, and recreation level…….………...39
Table 2. Microsatellite loci utilized in bobcat genetic analysis………………………………….40
Table 3. Information on all study animals, including capture date and location…….………..41
Table 4. LoCoH home range data……………………………………………………..……….42
Table 5. Results of univariate logistic regression models of bobcat telemetry data…….………43
Table 6. List of 15 *a priori* models run in generalized linear mixed models (GLMM)…………44
Table 7. Results from selected GLMM of bobcat presence…………………………….……..45
Table 8. Assigned habitat suitability values utilized in connectivity assessment………………..45
Table 9. Linkage status assessment with primary concerns for connectivity……………………46

EXECUTIVE SUMMARY

Our assessment of connectivity using bobcat movement and habitat use through camera, mortality, telemetry, and genetic data indicate that while functional connectivity is intact in some areas of the San Diego MSCP preserve network, data revealed that connectivity is impaired in other areas. Our connectivity assessment suggests:

- Overall, there is evidence of connectivity in the inland and coastal areas of the MSCP network that we sampled.
- Genetic analysis showed some degree of genetic differentiation between coastal bobcats west of I-15 and inland animals to the east, but did not indicate subpopulation differentiation has occurred. This supports the assertion that the coastal and inland areas have some level of connectivity.
- Movement analyses (camera and telemetry) showed direct use of five of seven linkages that were monitored. Detected movement was highest in Linkage 6-7, Linkage 8-10, and Linkage 5-6.
- For linkages not directly monitored, results from landscape models suggest that at least five other areas identified as putative linkages may have limited to no current connectivity, and another nine may only function partially. These limitations will likely increase under projected land use.
- Habitat alteration and recreation, in addition to other ecological variables, are currently affecting wildlife occupancy. These effects may increase under projected land use shifts.
- Heavily traveled secondary roads with traffic moving at high rates of speed may pose the largest threat to medium-wide ranging wildlife species attempting to move between core conserved areas, especially from coastal to inland areas. Roadkill mortality appears to increase with seasonal increases in animal movement.
- Projected habitat shifts resulting from climate change did not lead to substantial changes in habitat suitability or effective distance between preserves. However, future land use plans that lead to increased areas of altered use categories are likely to reduce habitat suitability in and around inland preserves.

ACKNOWLEDGEMENTS

We are grateful to a number of people for their contributions that made this research possible. First and foremost, our collaborators from the United States Geological Survey (USGS) Western Ecological Research Center, Erin Boydston and Lisa Lyren, provided invaluable assistance with equipment, proposal and report review, project design, field assistance, management of one of our primary volunteers, as well as expertise and advice (and a dose of good humor when inevitable problems arose) on all aspects of the project. We are appreciative of the lab space and guidance provided by Holly Ernest, as well as the expertise provided by lab manager, Lisa Dalbeck, from the Wildlife Genetics Lab at the University of California, Davis, where all our genetic analyses were run, and where Dr. Jennings was made to feel welcome again by all lab members. We appreciate the contribution of samples for genetic analysis by Winston Vickers and Walter Boyce from the University of California, Davis, and our collaborators, Erin Boydston and Lisa Lyren from USGS. Erik Stamm played a critical role in carrying out field activities from the beginning to the end, particularly for serving as the on-call bobcat handling assistant for all trapping efforts, managing cameras and volunteers when necessary, and for providing good company in the field. We had the good fortune of receiving excellent field help from both Preston Taylor and Marni Falk. Preston's excellent tracking skills and independent work facilitated project coordination and organization early-on. Marni's willingness to freely contribute her time, be flexible when necessary, and learn on the fly made her an excellent addition to our field team. A number of volunteers diligently managed our 36 camera stations. For these efforts, we are thankful to: Matt Willits, Renee Rivard, Marcus Collado, Don Endicott, Phoenix Von Hendy, Frank Sprinkle, Jim Hannan, and Scott McArthur. Marta Prat dedicated many hours in front of the computer entering data from our remote camera stations. Both Dovi Kacev and Catherine Tredick provided invaluable input on data management, analysis, and interpretation during this project. Our ability to carry out our field efforts would not have been possible without the cooperation of the preserve managers and rangers who helped provide access, shared information and data, and worked with us during our field efforts. In particular, we would like to recognize: City of San Diego employees Betsy Miller, Gina Washington, Lisa Wilson, and Thomas Stuhr; County of San Diego employees Jennifer Price, Cailin Hunsaker, Maureen Abare-Laudy, Justin Gibbons, Beth Dirksen and Paul Kucharczyk; California Department of Fish and Wildlife employees Jason Price, Karen Miner, and Randy Botta. We also appreciate the input and information provided by Barry Martin and Timothy Ann Hunt. The Fund for Animals Wildlife Center in Ramona, especially Christine Barton and Ali Crumpacker, became valuable partners during our research as they allowed us to collar several rehabilitated bobcats, and shared information and carcasses that came to their facility. Finally, we are grateful to Dave Bittner and the Wildlife Research Institute, Inc. in Ramona for providing freezer space, birds for trapping, and for sharing sightings of bobcats and roadkills.

INTRODUCTION

Current land management plans throughout the U.S. and Europe are designed to protect biodiversity by establishing a network of core habitat areas that are connected via linkages (Nelson *et al.* 2003). The central principle 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 like roads and housing developments. Landscape connectivity allows for movement among patches of suitable habitat, reduces the chance of extinction and effects of demographic stochasticity on small populations (Brown and Kodric-Brown 1977), and maintains gene flow between populations in patchy landscapes (Simberloff *et al.* 1992). 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 changing climate and altered disturbance regimes (Hannah *et al.* 2002, Heller and Zavaleta 2009).

In southern California, this landscape-scale network approach has been adopted in response to the widespread habitat conversion and fragmentation that has resulted from intense development (Riverside County 2003, Ogden 1996). Although the direct effects of anthropogenic landscape alteration, namely habitat loss and fragmentation, are paramount in this region (Crooks 2002, Beier *et al.* 2006, Soulé 1991), the potential for large scale shifts in vegetation and habitat types as a result of climate change may present an equally large risk to ecological networks.

General predictions from numerous climate models for the western United States suggest that temperatures will increase, there may be an increase in aridity (Westerling *et al.* 2003), and an overall reduction in rainfall (Hannah *et al.* 2002). These conditions are likely to extend fire seasons and increase fire frequency (Swetnam and Betancourt 1998, Brown *et al.* 2004). These predicted shifts in vegetation distribution and more frequent and/or severe wildfires driven by drier summers and earlier Santa Ana seasons (Miller and Schlegel 2006) may result in large-scale vegetation type conversion to non-native annual grasslands (Bachelet *et al.* 2001, Lenihan *et al.* 2003) and reductions in standing water availability.

All of these projected changes may have direct and indirect (*i.e.* food web) effects on wildlife. Temperature shifts may drive migration upslope to cooler climates (Hughes 2000) or westward to areas with greater marine influence and lower temperatures. Some species or individuals, such as females rearing young, may need improved access to water sources in the form of dense riparian areas and perennial streams, which are found in western portions of San Diego County. Whatever the response, shifts in distribution and habitat use can present a fundamental challenge to the currently designated landscape conservation network.

One of the central sources of uncertainty regarding how wildlife will respond to climate change is the lack of baseline data on current connectivity. In this study, we use bobcats as a model species to establish a foundation of knowledge on the present status of connectivity. Among wildlife species in southern California, bobcats respond negatively to habitat fragmentation, particularly when it results in smaller or more isolated habitat patches (Crooks 2002, Lyren *et al.* 2006, 2008, 2009). As a result, bobcats have been identified as a priority focal species for connectivity monitoring in southern California (Ogden 1996, Crooks 2002, County of San Diego 2004, South Coast Wildlands 2008). Bobcats also have the potential to function as an umbrella species, whereby conservation of viable populations and suitable habitat would confer protection to other species using similar habitats and movement corridors. Because bobcats are medium-ranging habitat generalists, studying their movement ecology and genetic diversity allows insight into landscape connectivity on a sub-regional scale. Because of their sensitivity to anthropogenic impacts to their habitat, bobcats also present an ideal system to study the effects of human recreation activities on wildlife. Understanding how this species responds to the complex interaction between human development and shifting habitats resulting from climate change is essential to preserve long-term connectivity and efficacy of the ecological network in this landscape.

Quantifying or assessing landscape connectivity, however, is non-trivial (Fagan and Calabrese 2006) given the context-dependent nature of connectivity (Crooks and Sanjayan 2006). Spatial and temporal scales may be different for wide-ranging species with a home range of tens of kilometers that responds to large-scale ecosystem processes versus a non-vagile species with a limited home range. Crooks and Sanjayan (2006) suggest connectivity assessments consider both physical and structural connectivity of an area, *i.e.* the physical arrangement of habitat on the landscape, as well as the response to that arrangement by individuals or species (Taylor *et al.* 1993, Tischendorf and Fahrig 2000a, 2000b). While conceptually this is intuitive, measuring both physical and functional connectivity is logistically difficult. There is a 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. Most recent efforts in connectivity assessment and planning utilize the concepts of resistance and cost (*sensu* Adriaensen *et al.* 2003) in evaluating functional connectivity. The former refers to the friction, or difficulty, in moving through each individual cell in the landscape and the latter represents the cumulative resistance encountered traveling through a linkage.

To assess the status of connectivity in a landscape-scale conservation network in southern California like the San Diego MSCP, this study was designed to collect robust, multi-faceted data to evaluate habitat use, response to human recreation, use of landscape linkages, and gene flow using bobcats as a focal species. The goal of the project was to establish the current state of landscape connectivity as well as connectivity under projected future conditions resulting from land use and climate shifts. Using bobcats as an indicator, we compared the use of urbanized and more natural habitats and determined how landscape features influenced home range size and distribution. Using these multiple, complementary datasets we asked the research questions: ***1) What is the current state of physical and functional connectivity in the MSCP? 2) Are there barriers to movement through linkages? If so, what and where are those barriers? 3) Does human recreational activity affect wildlife use in habitat cores? 4) How is movement across the landscape likely to change under climate change and land use projections?***

METHODS

Data Collection

Study Area

This study was conducted within the San Diego Multiple Species Conservation Plan Area in southern California across three sites, the Peñasquitos /SR56 area representing fragmented, coastal habitats, the SR67 Corridor between Lakeside and Poway, and the Ramona/SR78 area (Figure 1). The natural habitats and protected open space in the area are primarily publicly-owned, and include Los Peñasquitos Canyon Preserve, Black Mountain Open Space, Sycamore Canyon and Goodan Ranch Preserves, Boulder Oaks Preserve, San Vicente Highlands Preserve, Iron Mountain, San Dieguito River Park lands, and a portion of the Cleveland National Forest in Pamo Valley, north of the town of Ramona. These areas are also centered on major transportation corridors that cross the preserve networks, specifically SR56 near the coast, SR67 inland, and SR78 to the north.

Elevation across the three study sites ranged from sea level at the coast to 1000 m in the inland foothills. Habitat type 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*) 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. The Mediterranean-climate of the study region is characterized by hot, dry summers and mild, wet winters with precipitation often less than 300 mm.

Remote Cameras

To measure animal distribution, quantify occupancy across the MSCP, and consider the effect of recreation on animal distribution, remote camera stations were established across the study area in locations ranging from internal preserve cores to linkage areas and road crossings (Figure 2). Placement of the 36 camera stations was established on a 2 km grid, based on the minimum expected home range for a bobcat in urbanized landscapes in southern California. Locations for 12 cameras in each of the three study areas were selected to represent an equal sampling of the landscape features listed above, as well as a range of recreational use intensity (Table 1). We primarily utilized two types of cameras, the Cuddeback Expert white-flash camera (Cuddeback, Green Bay, WI, USA) and the LTL Acorn 5210A940 infrared camera (Old Boys Outdoors, Stone Mountain, GA, USA). As a result of theft, vandalism, and equipment failure, some of the older model Cuddeback Expert cameras were eventually replaced with Cuddeback Attack cameras. Cameras were deployed between November 30, 2011 and March 16, 2012 and were run for periods ranging from nine to 12 months. Cameras were set to capture images 24 hours per day, logging over 300,000 images from the 36 stations. Images were manually processed to identify species in each photo and entered into the program Camera Base 1.6 (Tobler 2012), an Access-based database for camera data and photo management.

Mortality Assessment

During the project, we identified and mapped any roadkilled bobcats reported by the public, cooperators, or project staff. Roadkill locations identified prior to the project period were also incorporated into our mapping. If possible, the carcass was collected and stored for necropsy where we collected a variety of samples to be stored for genetic analysis and for possible future use (*e.g.* anticoagulant screening of blood samples). We also collected a number of bobcat carcasses provided by the wildlife rehabilitation center, Fund for Animals Wildlife Center in Ramona, CA. Any patients that arrived and did not survive were stored for us, which included a number of animals that succumbed to notoedric mange. For all carcasses, we recorded cause of death (if known or identifiable), date of collection, sex, weight, body condition, and size. These data are now incorporated into the long-term bobcat mortality database managed by collaborators Lisa Lyren and Erin Boydston, United States Geological Survey – Western Ecological Research Center.

Animal Capture and Telemetry

Bobcats (n = 17) were trapped in baited cage traps (61cm x 43cm x 109cm) and sedated with a combination of ketamine HCl and xylazine HCL. All trapping, collaring, and tracking efforts were conducted by San Diego State University project staff (California Department of Fish and Game Scientific Collecting Permit #SCP-009632, SDSU Animal Protocol # 10-09-027L) between 2009 and 2012. Animals were weighed, measured, ear tagged, and fitted with one of two GPS collar brands (TCG181 or TCG271, Sirtrack Ltd., Havelock North, New Zealand; Quantum 4000, Telemetry Solutions, Concord, California, USA). During animal processing, we opportunistically collected all samples with the potential for future beneficial use. Blood, tissue, and buccal swab samples were taken from captured individuals for genetic testing to examine genetic connectivity across the project area.

Collars were set to collect fine-scale movement, gathering locational fixes eight times per day 5 days/week and 48 times per day 2 days/week, to track individual movement in relation to cores, linkages, potential barriers, human development over the course of six to nine months. Data were retrieved from collars with remote download, or stored-on-board until retrieval through recapture or a timed remote drop-off component in the collar. Data were checked and filtered for inaccurate and erroneous locations prior to analysis, and all locations with poor quality, undefined location (1-dimension or 1d) fixes were removed.

Genetic Sampling

To evaluate the functional connectivity (*i.e.* gene flow) across the sampled area of the MSCP, we collected tissue samples from a total of 62 bobcats gathered from a combination of live trapping, roadkill, and from assembling samples collected opportunistically by collaborators from areas in San Diego County. Genetic samples collected in the field were stored frozen at -20°C until they could be processed in the laboratory. All genetic lab work was conducted in the lab of Dr. Holly Ernest at UC Davis using microsatellite markers that had previously been tested on bobcat samples by Dr. Jennings in 2007 and 2008. Genomic DNA was extracted from blood and tissue using the QIAamp DNeasy blood and tissue kit, and from buccal swabs using the QIAamp DNA Mini and Blood Mini Kit (Qiagen Inc., Valencia, CA, USA), all following the manufacturer's protocols. We amplified 22 microsatellite loci (Table 2) for polymerase chain reaction (PCR). After initial optimization and testing, primers were grouped into multiplexes and prepared for PCR using the Qiagen Multiplex PCR Kit (Qiagen Inc., Valencia, CA, USA). PCR protocols followed the manufacturer's recommendations for the Multiplex PCR Kit. Thermal cycling parameters included an initial denaturing step at 95° C for 15 minutes, followed by 35 cycles of 94° C for 30 seconds; 54-60° C for 90 seconds; 72° C for 90 seconds, and then a final extension step at 72° C for 10 minutes. PCR product was analyzed using an ABI 3730 DNA Analyzer (Applied Biosystems, Foster City, CA, USA) and STRand software (Toonen and Hughes 2001). All PCR and genotyping was duplicated until two consistent results were obtained to reduce genotyping errors that can result in false alleles or allelic dropout.

Data Analysis

Remote Cameras and Occupancy Modeling

We analyzed all camera data using an occupancy modeling approach to identify the occupied rates within the monitored area. An occupancy approach does not monitor abundance;

rather it is used to establish the covariates that affect detection rates as well as the likelihood of species presence at each station. To analyze the camera data using this occupancy framework, we identified all photos of bobcats at all camera stations and created a capture history based on two week time intervals. If a bobcat was detected at a station within the selected two week period, it was recorded as a presence (1), and if not, as a non-detection (0). If the camera was not functioning or not present for a given time frame, a no-data value was recorded. Due a high level of missing values at four camera stations (78-BV, PV-SYC, 56-BV, and PQ-805) resulting from malfunctioning equipment, only 32 camera stations were included in the occupancy modeling. The time period analyzed included 18 two week periods between January and September 2012. These data were input in program PRESENCE 3.1 (Hines 2010) along with covariates for each camera station, including site type (core, bridge, culvert, or any linkage), recreation level (low or high), elevation, distance to major and local roads, and distance to water. We also recorded the proportional area in a 30m buffer around each camera station of each land use type and habitat type described in the habitat modeling section above. Survey covariates, or factors that may influence detection, included camera model at each station and whether the time period was during the wet or dry season. Models were run as single-season, assuming a closed population with no colonization or extinction. Model selection was based on the information theoretic approach using AIC, ΔAIC, and model weights (Burnham and Anderson 1998).

Mortality Assessment

We evaluated our mortality database to determine common causes of mortalities from the carcasses we salvaged during the study period. To visualize vehicle-caused mortalities for bobcats, we mapped all sites where mortalities occurred and identified common features of roadkill sites. With increasing numbers of mange mortalities during the project, we also established a database of incidences of mange reported to us by colleagues in the County, identified on remote cameras, or diagnosed during necropsy.

Home Range

Bobcat habitat use and range was calculated with a 95% adaptive local convex hull method (LoCoH, Getz and Wilmers 2004), using a=18,000 for bobcats. The LoCoH method is well-suited for constructing home ranges in landscapes with features that result in a distribution of point locations exhibiting sharp boundaries, corners, or holes, as is the case for the study area in southern California. The open spaces that make up the bobcat habitat in the study area are intersected by freeways, highways, and secondary roads, and abutted by housing developments and business parks, features generally avoided by bobcats. In addition to calculating the overall home range area with the LoCoH methods, we also calculated the proportion of home range area overlapping urban areas for an estimation of the degree to which animals may be constrained by unsuitable habitat adjacent to open space preserves.

Habitat Models

One component of our connectivity assessment was developed using habitat models. To model bobcat habitat suitability relative to the human landscape and other environmental factors, we used the telemetry data from bobcat GPS collars and evaluated the areas used relative to four different habitat categories: habitat features (habitat type and distance to water), anthropogenic landscape features (land-use type, distance to major roads, and distance to local roads), shifting fire-frequency (fire-return interval departure) and topographic variables (elevation). Habitat covariates were developed from the San Diego Association of Government's (SANDAG) vegetation data which were reformatted into seven groupings, water and wetlands (WAT), altered habitat (ALT), grasslands (GRS), shrublands (SHB), riparian areas (RIP), forested areas (FOR), and other (OTH), which included small areas of desert scrub. Additional information on methods employed can be found in Appendix A.

Based on the results of the habitat selection models, we evaluated the current state of landscape connectivity and the predicted state under projections of future climate and land use changes. There were three components to this assessment: habitat suitability, landscape resistance, and effective distance (*i.e.* cost-weighted distance). We followed established methods (Singleton *et al.* 2004, Beier *et al.* 2007, Spencer *et al.* 2010, Beier *et al.* 2011), and first identified landscape permeability by assigning habitat suitability values, based on empirical values from generalized linear mixed models (GLMMs), between ten (least suitable) and 100 (most suitable) to categories in the GIS raster layers based on the results of univariate modeling and the multivariate model for each species. The biological interpretation of these values, as suggested by Beier *et al.* (2007) is that 100 is equivalent to the best habitat with highest survival and reproductive success, 80 is the lowest value with successful breeding, 60 is associated with consistent use and breeding, 30 represents occasional use for non-breeding activities and anything below 30 is avoided (see Appendix B for more information on methods).

We calculated these surfaces both under current and future conditions, incorporating habitat shifts and land use changes to provide a comparison. Planned land use data from SANDAG's Series 12 Regional Growth Forecast (2050) provided input for projected shifts in land use. We also employed current and future habitat data developed from models established by Stralberg *et al.* (2009). The projected future vegetation classification models used Random Forest algorithms and were based on projections from two different climate models: NCAR CCSM3.0 (National Center for Atmospheric Research Community Climate System Model) averaged from 2038-2069 (478-610 ppm CO_2), and the GFDL CM2.1 (Geophysical Fluid Dynamics Laboratory Coupled Climate Model) averaged from 2038-2070 (478-615 ppm CO_2). When analyzed in our connectivity assessment, the difference between the two climate models was negligible, thus only results from the GFDL CM2.1 model are presented in comparison to the current vegetation condition. The vegetation projection models, like all climate models, are not perfect; the highest spatial resolution is 800 m grid cells and there is inherent uncertainty in modeling future scenarios. However, these vegetation classification models are a published and peer-reviewed product and represent the best available data at the present time.

Genetic Assessment

Data were initially assessed in the Excel Microsatellite Toolkit (Park 2001). Based on published findings of restricted gene flow in southern California (Riley *et al.* 2006, Lee *et al.* 2012), data were split into two putative subpopulations, coastal and inland, for analysis. The data were evaluated in Microchecker 2.2.3 (Van Oosterhout *et al.* 2004) to test for issues of stuttering, null alleles and allelic drop-out. GENEPOP on the Web (Raymond and Rousset 1995, Rousset 2008) was used to test populations for Hardy-Weinberg equilibrium and linkage disequilibrium. F_{ST} and population differentiation was calculated in GENEPOP, and followed by tests to estimate subpopulation differentiation (D_{est}) using Software for Measurement of Genetic Diversity (Crawford 2010) given recent criticisms of F_{ST} (Jost 2008). To evaluate the putative subpopulation structure we defined, we ran program STRUCTURE 2.3.3 2 (Prichard *et al.* 2000, Falush *et al.* 2003) to identify genetically distinct subpopulations (K). We ran a burn in of 10,000 and ran 1,000,000 Markov Chain Monte Carlo iterations. We tested K from 1 to 5 populations, and repeated the analysis 100 times for each K to verify the consistency of likelihood values between runs. In order to choose which value of K best fits our population we analyzed ln P(X|K) as suggested by the STRUCTURE manual (Prichard *et al.* 2000) as well as the ΔK method (Evanno *et al.* 2005).

RESULTS

During the course of the project, we handled 19 bobcats and collared 17, collected over 300,000 photos from camera stations, identified 24 roadkill locations, and processed 62 genetic samples.

Remote Cameras and Occupancy Modeling

Photos processed from the remote camera stations identified bobcats at all but two camera stations during 28 two-week sampling periods. An additional four stations only detected bobcats once during the camera monitoring. Stations with the lowest detection of bobcats included Iron Mountain, Mount Woodson, San Vicente Highlands, Upper Beelor Canyon, three crossings under SR78, Carmel Valley Road at Black Mountain, and Santa Luz at Camino del Sur. Stations with the greatest detections of bobcats (22-26 detections out of 28 sampling periods) included Goodan Ranch, McGonigle Canyon, and Boulder Oaks (see Appendix C for more information on model selection and results). Models suggested that bobcat detection was lower with the older model Cuddeback cameras, and occupancy was negatively associated with bridges, altered habitat, and camera stations within putative linkage zones compared to those in core conserved areas. Although not significant, we also found that bobcat occupancy rates were lower at stations with high recreation and at lower elevation (*i.e.* coastal) stations. Occupancy rates ranged from 0.66 at the Black Mountain Road bridge over Los Peñasquitos Creek to 0.91 at Boulder Oaks Open Space Preserve with higher occupancy rates overall in the inland study areas (Figure 3).

Although we have not yet quantitatively analyzed the patterns of species co-occurrence at remote camera stations, through our image processing, we observed a number of other species that were often detected at stations with frequent detection of bobcats, suggesting bobcats may serve as an indicator of connectivity for these species. Not surprisingly, species known to be tolerant of or associated with urbanized habitats and human activity, *e.g.* coyotes (*Canis latrans*), raccoons (*Procyon lotor*), striped skunks (*Mephitis mephitis*), and Virginia opossums (*Didelphis virginiana*), were detected at most stations, including those where bobcat detections were high. In addition, less common species like greater roadrunner (*Geococcyx californianus*), Western spotted skunk (*Spilogale gracilis*), long-tailed weasel (*Mustela frenata*), gray fox (*Urocyon cinereoargenteus*), mule deer (*Odocoileus hemionus*), and Cooper's hawk (*Accipiter cooperii*) were all observed at many of the stations with frequent bobcat detections. Of these, images of mule deer were repeatedly captured at many of the stations except for the culvert crossings under SR67 where there were only occasional images of mule deer. Beyond these commonly co-occurring species, we also obtained a number of puma images at several of our camera stations in the inland portions of our study area east of SR67.

Mortality Assessment

The primary sources of mortality we identified were vehicle collisions, followed by mange, caused by the felid-specific mange mite, *Notoedris cati*. We identified 24 roadkill locations (Figure 4) across San Diego County. Upon review of the data collected for each roadkill, we determined that the majority of these occurred on undivided, secondary roadways. Vehicles on these roadways often travel at high speeds but through terrain that may make detecting oncoming traffic difficult for animals attempting to cross over the roadway, as opposed to an underpass or culvert. In fact, a number of the roadkilled animals we collected were found near crossing structures, which they may have used rather than going over the road, if the structures had been better placed, not blocked with vegetation, or had appropriate wildlife fencing to direct animals into the crossing structure. Our data also suggest that many of the vehicle-caused mortalities occurred between late September and early March, during the bobcat breeding season. Increased movement activity and exploration out of home ranges in an attempt to find a mate may result in a greater number of crossing attempts resulting in the increased mortalities during this time period.

During the course of this study, we also identified mortality caused by what appeared to be a mange epizootic in the greater Ramona/SR67 area. From detection on cameras, reports from the public, and calls for assistance into the Fund for Animals Wildlife Center rehabilitation center, we counted approximately 21 unique individuals affected by moderate to severe mange between 2010 and 2012 between SR67, the San Diego Country Estates, and SR78 in San Pasqual Valley. Without intervention, all of these animals would eventually die from emaciation or secondary infection resulting from the mange. We provided these data to collaborators focused on studying the prevalence and impact of mange in southern California at University of California - Los Angeles, University of California – Davis, and the Santa Monica Mountains National Recreation Area (Foley *et al.*, in review).

Telemetry and Home Range Analysis

We handled a total of 19 bobcats (14 males, 5 females; Table 3), collared 17, and have retrieved data from eight of the collars. The duration of tracking lasted between 11 and 465 days. Over 12,000 point locations were gathered from seven male and one female bobcat (Figure 5). Radio collar loss or malfunction limited the data we were able to retrieve, although there are still three animals we will attempt to recapture in June 2013 after the kitten season has ended. Additional locations collected through manual triangulation of the VHF signal from each collar are still being processed to incorporate data from the individuals that experienced collar failure.

We calculated the Local Convex Hull (LoCoH) home ranges for each individual (Table 4, Figure 6) utilizing all points available for each animal, and found that the mean home range size was 5.15km^2. Home range size varied greatly between individuals with some animals traveling long distances between core areas. Overall, we found that the majority of landscape used by bobcats was classified as natural habitat. However, animals were found to move relative to the constraints of their surroundings, *e.g.*, bobcats in Los Peñasquitos Canyon had smaller home ranges than in other areas. Similarly, animals in this and other developed areas were found to use more urban habitat than average. In comparison, the animals tracked in Pamo Valley had almost no urban association, showing a link between habitat use and environmental constraints.

Habitat Models

We created 15 different *a priori* models of bobcat presence incorporating combinations of habitat, land use, human development, and topography to identify which variables were most influential in explaining bobcat presence (Table 5). Models including elevation, all habitat variables, and all land use variables outperformed all other models (AICw_i > 0.999; Table 6).

The model output indicates that bobcat presence was most closely associated with water/wetland habitats, low elevation, and distance from major and local roads, as well as avoidance of shrublands and urban habitat (Table 7). Although our fire-return interval departure variable did not provide significant explanatory power in our models to predict bobcat presence, our previous research has found this to be a critical variable in analysis of movement data from Orange County that is often overlooked, resulting in overestimations of connectivity (Jennings 2013). Although we did not carry this variable forward in our analyses, it would be useful to continue monitoring fire-return intervals and the potential for vegetation type conversion across the preserve network.

Connectivity Assessment

To assess connectivity, we created three different raster layers based on the empirical data from our modeling efforts: suitable habitat, landscape resistance, and cost-weighted distance. Initially, habitat suitability values for each variable category that was determined to be significant predictor of bobcat presence (land cover, elevation, distance to roads, distance to water, and habitat) were established based on our modeling results (Table 8). Under current climate and land use conditions, our analyses suggest that habitat suitability is relatively high in and around core areas, more so in inland areas than the more fragmented coastal portions of the preserve network. Through our cost-weighted distance connectivity analysis, we found that connectivity among core areas is likely limited in a number of locations, *e.g.* Linkage 1-2b, Linkage 2-3a, Linkage 4-5, Linkage 6-7, Linkage 12-13, and Linkage 5-13 (all linkage designations are those identified in the Connectivity Monitoring Strategic Plan for the San Diego Preserve System 2011). Through our camera and GPS telemetry, we also found that some linkages, or segments of designated linkages do appear to serve as true conduits of animal movement among core areas. This includes Linkage 8-10, the eastern segment of Linkage 11-12, the western segment of Linkage 5-8, and to some degree, Linkage 5-6 under SR67.

In response to projected climate change (GFDL model between 2038 and 2070) and planned land use changes projected by SANDAG (Figure 7), we found little evidence of significant changes in the amount or distribution of suitable habitat resulting from climate conditions. However, the shifts in projected land use, particularly to altered categories of use in inland backcountry areas caused declines in suitable habitat, both within preserve cores, as well as in the areas between protected lands identified as putative landscape linkages.

When we calculated the effective distance between protected lands, the average effective distance for bobcats to travel between protected lands did not appear to change significantly in geographic position or overall value (Figure 8). However, current choke points that are already locations of concern necessary for connecting core preserve lands are likely to become more impacted in the future, further limiting connectivity through these linkages. In particular, several linkage zones identified by the MSCP Connectivity Strategic Plan (2011), *e.g.* Linkage 10-11, Linkage 12-13, Linkage 6-7, Linkage 5-13, Linkage 4-5, Linkage 1-2b, and Linkage 2-3a, may become impassable under future land use development. These linkages represent important connections both north to south and east to west and likely represent highly restricted movement from core preserves in more fragmented urban areas to larger blocks of intact habitat.

Genetic analysis

A total of 62 genetic samples were processed and genotyped and then separated into two putative bobcat subpopulations, a coastal and an inland unit, for analysis (Figure 9).

Microchecker analysis identified that there was no evidence of null alleles in the coastal population, but potential evidence for four loci in the inland population (FCA45, FCA90, Lc110, FCA35). Tests for linkage disequilibrium identified 22 potentially linked loci pairs. FCA35, FCA8, FCA90, and Lc111 were found to be in linkage disequilibrium in both subpopulations, so were eliminated from further analyses. Tests to determine whether each population was in Hardy-Weinberg equilibrium revealed that the coastal population was in equilibrium ($p = 0.0654$) and that the inland populations may be out of equilibrium ($p < 0.001$). This finding may be a result of skewed data, with a larger number of related individuals in inland areas sampled during live captures within a small geographic area. Analysis of relatedness is necessary to test this hypothesis. Tests of genotypic variation suggested that the coastal and inland populations are genetically distinct ($X^2 = 70.20$, df = 36, $p < 0.001$), and that distribution of alleles at all 18 loci differed significantly between coastal and inland populations. We also observed lower allelic richness in coastal bobcat populations, suggesting isolation in fragmented coastal preserves may be limiting gene flow. However, further analyses indicate that the samples tested were not from two distinct subpopulations. Both analyses of subpopulation differentiation ($D_{est} = 0.003$, $F_{ST} = 0.006$) indicate low genetic differentiation between the putative subpopulations. The analysis of the results from our STRUCTURE runs from K= 1 to K=5 also reveal that the samples tested were from a single panmictic population (Figure 10).

DISCUSSION

Our assessment of connectivity using bobcat movement and habitat use through camera, mortality, telemetry, and genetic data indicate that while functional connectivity is intact in some areas of the San Diego MSCP preserve network, data revealed that connectivity is impaired in other areas. Our connectivity assessment suggests:

- Overall, there is evidence of connectivity in the inland and coastal areas of the MSCP network that we sampled.
- Genetic analysis showed some degree of genetic differentiation between coastal bobcats west of I-15 and inland animals to the east, but did not indicate subpopulation differentiation has occurred. This supports the assertion that the coastal and inland areas have some level of connectivity.
- Movement analyses (camera and telemetry) showed direct use of five of seven linkages that were monitored. Detected movement was highest in Linkage 6-7, Linkage 8-10, and Linkage 5-6.
- For linkages not directly monitored, results from landscape models suggest that at least five other areas identified as putative linkages may have limited to no current connectivity, and another nine may only function partially. These limitations will likely increase under projected land use.
- Habitat alteration and recreation, in addition to other ecological variables, are currently affecting wildlife occupancy. These effects may increase under projected land use shifts.
- Heavily traveled secondary roads with traffic moving at high rates of speed may pose the largest threat to medium-wide ranging wildlife species attempting to move between core

conserved areas, especially from coastal to inland areas. Roadkill mortality appears to increase with seasonal increases in animal movement.

- Projected habitat shifts resulting from climate change did not lead to substantial changes in habitat suitability or effective distance between preserves. However, future land use plans that lead to increased areas of altered use categories are likely to reduce habitat suitability in and around inland preserves.

Current levels of connectivity

Genetics and movement data (camera and telemetry) suggest that there is some level of connectivity between the inland and coastal areas of the MSCP we studied, and varying levels of connectivity between core conserved areas within both the east and west (Figure 11, Table 9).

Genetics

Our analysis of genetic samples revealed some level of genetic differentiation between coastal and inland bobcats (Figure 9) at the loci we analyzed, but this level of differentiation has not led to subpopulation structure. This disparity could be the result of two factors, one related to our sample size and distribution, the other associated with population size and genetic drift. We sampled approximately 30 individuals in coastal (closest to coast) and inland (animals east of Interstate 15), however, it is possible that we did not have sufficient sample sizes to detect subpopulation structuring between these areas. It is also possible that the preserves closest to the coast (and farther from I-15) are smaller and more isolated and may in fact, have limited gene flow with outside areas.

The disparity in our results for genetic differentiation may also be the result of limited genetic drift in San Diego County's coastal preserves. Smaller populations are likely to experience higher rates of genetic drift and may show differentiation in fewer generations. In San Diego's coastal areas where we collected genetic samples, the preserves are larger blocks of land and are slightly less isolated than the sampling locations from the previous research in the Santa Monica Mountains (Riley *et al.* 2006) or Orange County (Lee *et al.* 2012). Previous research (Riley *et al.* 2006, Lee *et al.* 2012) has found bobcat subpopulation structuring and limited gene flow across major freeways in southern California. In both these studies, the preserves on at least one side of the freeway are small and relatively isolated from other preserves, differing from the slightly larger and more connected preserves in San Diego's coastal preserves.

Movement data

We have direct camera and telemetry evidence that some movement is occurring between coastal and inland preserves. We documented bobcats moving under I-15 (Figure 5), which may be enough to allow for gene flow between preserves to the east and west of this potential barrier. However, the flow from that point to areas farther inland, such as Sycamore Canyon, appear to be limited by development and altered habitat between I-15 and preserves just west of SR67, with only one bobcat detection at Upper Beelor Canyon, one of the few corridors of open space between coastal and inland zones. We observed a number of animals crossing SR67 through culverts (Figure 3), but also collected roadkilled animals in the area (Figure 4), which represent a barrier to connectivity if the crossings are not fenced and improved, especially as traffic is likely to increase along this transportation corridor in the future. Along the northern east-west linkage, some movement was documented through our Pamo Valley/SR78 study area (Figure 5). In this case, we observed individuals moving along the eastern part of the linkage within San Pasqual Valley, but were not able to monitor the zone to the west through Lake Hodges that is necessary to link eastern to western preserves in this area. Numerous crossings of SR78 were documented in at least one of the four underpasses monitored (Figure 3), but poor placement of culverts, agricultural habitat, and high levels of human movement appeared to restrict movement through the other three crossings.

Within the coastal study area, our data indicate that there is functional movement, at least between preserves on either side of SR56. We observed not only numerous crossings under the three bridges we monitoring along SR56, but movement and behavior (*e.g.* adults with kittens, foraging individuals) suggesting bobcats are utilizing the natural habitat under these bridges as part of their home ranges rather than just as movement corridors. VHF telemetry documented the movement of one individual from Los Peñasquitos Canyon to the Black Mountain Open Space region, but until we retrieve GPS collar data, we will not know which of the bridges he used and whether it was through the putative linkage identified through McGonigle Canyon.

Connectivity between the north and south inland areas appears to be the most problematic for wildlife movement. We were only able to monitor one culvert along SR67 in the region of Mount Woodson, because there is only one available for crossing. This camera station had almost no bobcat activity documented (Figure 3), and we detected at least one roadkill along this section of roadway. While movement to the south through the Scripps-Poway Parkway wildlife tunnel was regularly documented, there is still a large amount of unprotected and developed habitat for animals to move through to get to northern conserved lands. In particular, the crossing of Poway Road appears to be a challenge with multiple roadkills (Figure 4) observed along the winding stretch of road just west of SR67. One animal was tracked as he moved from the northern preserves in San Pasqual Valley up to the Ramona Grasslands, but he did not proceed south to Mount Woodson or to cross SR67 toward Iron Mountain (Figure 5).

Habitat models

Our habitat suitability models, as well as the cost-weighted distance connectivity assessment provide a means of comparing the likelihood of connectivity across the landscape. We found evidence of lower quality habitat both within core areas of the MSCP and in associated putative linkages, namely, Linkage 8-10, 5-8, 2-3a, and 1-2b (Figure 7). While some animals may be willing to use and traverse these unsuitable areas, there are still questions of whether enough animals will do so, whether those that attempt the crossing will be successful, and whether they will find suitable and unoccupied habitat at the other end of the linkage. The cost-weighted distance analysis similarly identified a number of areas where additional linkages are needed as the resistance/cost between one preserve to the next likely limits connectivity (see notations on Figure 8).

Potential impediments to connectivity

Our analyses reinforce the idea that development (current and projected), human use, and road crossings may limit movement in certain areas of the San Diego MSCP preserve network.

Recreation

The occupancy modeling of the remote camera stations across the study area revealed that bobcat occupancy was lowest in areas outside of core conserved areas, in altered habitats, and in the coastal area of our study. While the effect of recreation was not identified as a primary factor, this may have been the result of limited power to detect these effects. We did find overall fewer total detections of bobcats at the camera stations with the highest recreation like Iron Mountain, Los Peñasquitos Canyon, and at the San Dieguito River trailhead at Bandy Canyon Road and SR78 (Figure 3). In fact, only three photos of bobcats were taken at the Iron Mountain station, where tens to hundreds of people passed daily, over the course of the year-long sampling. In contrast, 32 bobcat detections were gathered at camera 67-C4 at the culvert along SR67 just below the hiking trail at Iron Mountain. It is likely that our coarse categorization of recreation into high and low levels to assess its impact on species occupancy oversimplified a more complex interaction between wildlife and human recreation, which has been documented in other studies of the effects of recreation on mammalian carnivore species (George and Crooks 2006, Reed and Merenlender 2008). A more detailed analysis of the recreation data we gathered, including rates, types, and temporal patterns of both recreation and animal detections, could yield results that provide more guidance on the effect of recreation in and around linkages.

Road mortality

Our mortality assessment determined that a high number of mortalities occurred on highly traveled secondary roads where vehicle speeds are often > 50 mph (Figure 4). A number of roadkilled bobcats we collected were found along guardrails near culverts or tunnels suggesting that the animal elected to attempt to cross over the road, rather than go through the crossing. This may be related to crossing type, placement, or simply a result of inadequate or inappropriate wildlife fencing to direct the animal into the crossing. We observed poorly placed (*e.g.* not connected to the crossing structure) and broken fencing, barbed wire fences, and no fencing at a number of the camera stations along SR67. In fact, the SR67 study area faces the greatest challenges for road crossings with high roadkill numbers along secondary roads in an area bounded by highways, virtually on all sides.

Other mortality sources

In addition to limitations on movement across or under roads, there appear to be additional stressors to animals in this area as evidenced by the mange epizootic observed during the study. Our assessment indicated that, as in other areas of southern California (Riley *et al.* 2007), mange is a concern for San Diego bobcat populations. While we were not primarily focused on assessing this disease in our bobcat populations, there is a need for continued cooperation and collaboration with other researchers to provide information about ongoing issues related to mange in San Diego County. It is worth noting that this and other disease outbreaks may be related to connectivity as disease may spread more readily in constrained, highly developed areas, *e.g.* Los Peñasquitos Canyon, as has been observed in other areas of southern California (Riley *et al.* 2007, Foley *et al.*, in review). Research on the prevalence of mange in southern California has detected a correlation between incidences of mange and bobcat exposure to anticoagulant rodenticides which may occur both in highly urbanized areas as well as areas of exurban development where housing and wildlands are intermixed to a greater degree. The apparent mange epizootic we observed during our study supports this relationship. The large projected increase in altered land use categories from the SANDAG models may have indirect effects on the health of wildlife populations beyond the immediate impacts of habitat fragmentation and a decline in habitat suitability.

Development

Bobcat movement and activity in more heavily impacted and fragmented areas of the MSCP network (Los Peñasquitos Canyon into Carmel Valley/Rancho Santa Fe) indicate that connectivity may be particularly constrained in these areas (Table 4, Figure 6). No tracked bobcats traveled beyond the bounds of open space into urban neighborhoods on the edges of Los Peñasquitos Canyon. Indeed, the large number of males captured in this area suggests that urban animals may be experiencing home range pile-ups (*sensu* Riley *et al.* 2006) and occur at higher densities when alternatives for dispersing are limited. Although many bobcats appeared to be tolerant of or adapted to the high level of human activity and urbanized landscape in the coastal cores, this response may be a result of limited options to avoid these areas. Certainly, dispersal remains a concern for bobcats and for the viability of protecting populations of a variety of species in this highly fragmented area. In comparison, bobcats in the north inland area around Pamo Valley, San Pasqual Valley, and SR78 have ample habitat to move through, and as a result, these animals successfully avoided development and areas with increased levels of human activity.

Connectivity under climate change and land use projections

When we evaluated connectivity under potential future climate conditions, we did not see a substantial change in habitat suitability. This may be a result of the coarse scale at which the habitat models were developed, similar to most current climate change models. More notably, when we incorporated data on planned land use for 2050, we saw a marked decline in suitable habitat, particularly in the inland areas surrounding the SR67 study area. There were six linkages identified that displayed the most obvious changes in suitability, which also happened to be areas already experiencing limited movement, *e.g.* Linkages 6-13, 5-13, 6-7, 2-3a, 2-3b, and 1-2b (see notations on Figure 7).

The assessment of connectivity using cost-weighted distance revealed a slight increase in the effective distance required to traverse certain areas under future conditions. The areas of greatest concern with regard to connectivity appear to be Linkages 10-11, 12-13, 6-13, 5-8, 5-13, 4-5, 1-2b, and 2-3a (see notations on Figure 8). Identifying site-specific corridors in these areas with potential alternatives is the first step to re-establishing connectivity at these locations. Then, on a case-by-case basis, steps to improve each linkage can be developed. As higher resolution climate models are released for the MSCP region, these analyses should be repeated. By continuing to monitor both the change in habitat and in land use, local land management agencies will have a greater ability to successfully create and protect connectivity.

Future Directions

The first steps to begin addressing current issues with connectivity include early corridor identification based on empirical data, rather than mapping exercises or expert opinion. We have taken this important first step in analyzing connectivity for San Diego County's ecological network with this synoptic assessment. However, further investigation prior to developing concrete management recommendations is warranted. There are many methods available and in use to assess connectivity, and there is no scientific consensus as to the ideal method (Beier *et al.* 2011). Instead, many experts recommend an ensemble approach, whereby several methods are applied, *e.g.* CircuitScape, MaxEnt, and Zonation programs. Results from these analyses can then be compared to identify areas of agreement that require management action to protect or re-establish connectivity. Integrating data from other ongoing connectivity studies in the region that use both empirical and analytical approaches, it would be possible to evaluate connectivity for a wider range of organisms. While bobcats serve as an indicator for connectivity, a synthetic analysis that incorporates connectivity from other organisms into a comprehensive assessment is an important next step. Utilizing a robust and diverse data set to identify site-specific corridors will also allow us to assess the remainder of MSCP and MSHCP (planned and in-progress) where site-specific data are not currently available.

Once these thorough assessments have been completed, planning efforts can identify and prioritize action for each given corridor. These actions may be to acquire land, restore habitat, protect habitat, and even create corridor redundancy to allow for a changing landscape given uncertainty of future conditions. Considering the potential impact of recreation on bobcat activity patterns, as well as what has been encountered by other studies (George and Crooks 2006, Reed and Merenlender 2008), limiting recreation either temporally or spatially in critical crossing and linkage areas may be another step to consider in re-establishing and protecting connectivity. As this work is being conducted in an ever-changing environment with new and improved information and ways of assessing information constantly evolving, it is important that connectivity assessments be seen as an iterative process. We recommend that monitoring and direct management action be taken in locations that were identified as areas where connectivity was impaired. These areas should continue to be re-evaluated based on projected future change, as well as continued monitoring data, as more information becomes available. Taking a proactive and empirically-based approach to assessing connectivity at this sub-regional scale will allow San Diego’s preserve network to continue moving forward as a functioning land, habitat, and species conservation plan, while allowing for future change in a planning environment challenged by the nature of fixed spatial extents and a dynamic landscape.

REFERENCES

Aarts, G., J. Fieberg, and J. Matthiopoulos. 2012. Comparative interpretation of count, presence-absence and point methods for species distribution models. Methods in Ecology and Evolution 3: 177–187.

Adriaensen, F., J. Chardon, G. deBlust, E. Swinnen, S. Villalba, H. Gulinck, and E. Matthysen. 2003. The application of ‘least-cost’ modeling as a functional landscape model. Landscape and Urban Planning 64: 233–247.

Bachelet, D., R.P. Neilson, J.M. Lenihan, and R.J. Drapek. 2001. Climate change effects on vegetation distribution and carbon budget in the United States. Ecosystems 4: 164-185.

Barrows, C.W., K.D. Fleming, and M.F. Allen. 2011. Identifying habitat linkages to maintain connectivity for corridor dwellers in a fragmented landscape. The Journal of Wildlife Management 75(3): 682-691.

Beier, P., K. Penrod, C. Luke, W. Spencer, and C. Cabañero. 2006. South Coast missing linkages: restoring connectivity to wildlands in the largest metropolitan area in the United States. Pages 555–586 in K. R.Crooks and M. A.Sanjayan, editors. Connectivity conservation. Cambridge University Press, Cambridge , United Kingdom .

Beier, P., D. Majka, J. Jenness. 2007. Conceptual Steps for Designing Wildlife Corridors. <www.corridordesign.org> (accessed October 2012).

Beier P., W. Spencer, R.F. Baldwin, and B.H. McRae. 2011. Toward best practices for developing regional connectivity maps. Conservation Biology 25: 879–892.

Beyer, H.L. 2012. Geospatial Modelling Environment (Version 0.7.1.0). (software). URL: http://www.spatialecology.com/gme.

Boitani, L., A. Falcucci, L. Maiorano, and C. Rondinini. 2007. Ecological networks as conceptual frameworks or operational tools in conservation. Conservation Biology 21(6): 1414-1422.

Bolker, B.M., M.E. Brooks, C.J. Clark, S.W. Geange, J.R. Poulsen, M.H.H. Stevens, and J.-S.S. White. 2009. Generalized linear mixed models: a practical guide for ecology and evolution. Trends in Ecology and Evolution 24: 127–135.

Brown, J. H., and A. Kodric-Brown. 1977. Turnover rates in insular biogeography: effect of immigration on extinction. Ecology 58: 445-449.

Brown, T. J., B. L. Hall, and A. L. Westerling. 2004. The impact of twenty-first century climate change on wildland fire danger in the western United States: An applications perspective. Climatic Change 62:365-388.

Burnham, K.P., and D.R. Anderson. 2002. Model selection and model inference. Second edition. Springer-Verlag, New York, New York, USA.

Burdett, C.L., K.R. Crooks, D.M. Theobald, K.R. Wilson, E.E. Boydston, L.M. Lyren, R.N. Fisher, T.W. Vickers, S.A. Morrison, and W.M. Boyce, W.M. 2010. Interfacing models of wildlife habitat and human development to predict the future distribution of puma habitat. Ecosphere 1: 1–21.

Carmichael, L.E., Clark W., Strobeck C. 2000. Development and characterization of microsatellite loci from lynx (*Lynx canadensis*), and their use in other felids. Molecular Ecology 9:2197-2198.

Clark, R.G., and T.C. Stevens. 2008. Design and analysis of clustered, unmatched resource selection studies. Journal of the Royal Statistical Society, Series C, Applied Statistics 57: 535–551.

County of San Diego. 2004. "MSCP 2003 Annual Report." San Diego: Multiple Species Conservation Program, Department of Planning and Land Use, County of San Diego.

Crawford, N.G. 2010. SMOGD: software for the measurement of genetic diversity. Molecular Ecology Resources 10:556-557.

Crooks, K.R. 2002. Relative sensitivities of mammalian carnivores to habitat fragmentation. Conservation Biology 16: 488-502.

Crooks, K.R. and M.A. Sanjayan. 2006. Connectivity Conservation. Cambridge University Press, Cambridge, UK.

Evanno, G., Regnaut S., Goudet J. 2005. Detecting the number of clusters of individuals using the software STRUCTURE: a simulation study. Molecular Ecology 14:2611-2620.

Fagan, W.F. and J.M. Calabrese. 2006. Quantifying connectivity: balancing metric performance with data requirements. Connectivity Conservation (eds K.R. Crooks & M. Sanjayan), pp. 297–317. Cambridge University Press, Cambridge.

Faircloth, B.C., Reid A., Valentine T., *et al.* 2005. Tetranucleotide, trinucleotide, and dinucleotide loci from the bobcat (*Lynx rufus*). Molecular Ecology Notes 5:387-389.

Falush, D., Stephens M., Pritchard J.K. 2003. Inference of population structure using multilocus genotype data: Linked loci and correlated allele frequencies. Genetics 164:1567-1587.

Foley, J., Serieys L., Stephenson N., Riley S., Foley C., Woods L., Jennings M., Wengert G., Vickers W., Boydston E., Lyren L., Crooks K., Moriarty J., and Clifford D. In Review. The ecology of notoedric mange. Journal of Wildlife Management and Wildlife Monographs.

George, S.L. and K.R. Crooks. 2006. Recreation and large mammal activity in an urban nature reserve. Biological Conservation 133: 107-117.

Getz, W.M. and C.C. Wilmers. 2004. A local nearest-neighbor convex-hull construction of home ranges and utilization distributions. Ecography 27: 489-505.

Gillies, C.S., M. Hebblewhite, S.E. Nielsen, M.A. Krawchuk, C.L. Aldridge, J.L. Frair, D J. Saher, C.E. Stevens, and C.L. Jerde. 2006. Application of random effects to the study of resource selection by animals. Journal of Animal Ecology 75: 887–898.

Hann, W.J., and D.L. Bunnell. 2001. Fire and land management planning and implementation across multiple scales. International Journal of Wildland Fire 10: 389-403.

Hannah, L., G.F. Midgley, and D. Millar. 2002. Climate change-induced conservation strategies. Global Ecology and Biogeography 11: 485–495.

Hines, J.E. 2010. PRESENCE3–software to estimate patch occupancy and related parameters. Version 3.1. USGS--PWRC. Available from URL: http://www.mbr--pwrc.usgs.gov/software/presence.html

Jennings, M. K. 2013. Landscape dynamics in Southern California: understanding mammalian carnivore response to fire and human development. [Ph.D. Dissertation]. University of California, Davis and San Diego State University.

Jost, L. 2008. G_{ST} and its relatives do not measure differentiation. Molecular Ecology 17(18):4015-4026.

Lee, J.S., E.W. Ruell, E.E. Boydston, L.M. Lyren, R.S. Alonso, J.L. Troyer, K.R. Crooks, S. VandeWoude. 2012. Gene flow and pathogen transmission among bobcats (*Lynx rufus*) in a fragmented urban landscape. Molecular Ecology 21(7):1617-1631.

Lenihan, J. M., R. Drapek, D. Bachelet, and R. P. Neilson. 2003. Climate change effects on vegetation distribution, carbon, and fire in California. Ecological Applications 13:1667-1681.

Lyren, L. M., R. S. Alonso, K. R. Crooks, and E. E. Boydston. 2009. Evaluation of functional connectivity for bobcats and coyotes across the former El Toro Marine Base, Orange County, California: Administrative report delivered to cooperator Jan. 20, 2009, 179 p.

Lyren, L. M., R. S. Alonso, K.R. Crooks, and E. E. Boydston. 2008. GPS telemetry, camera trap, and mortality surveys of bobcats in the San Joaquin Hills, Orange County, California. U.S. Geological Survey Report, 134 p.

Lyren, L. M., G. M. Turschak, E. S. Ambat, C. D. Haas, J. A. Tracey, E. E. Boydston, S. A. Hathaway, R. N. Fisher, and K. R. Crooks. 2006. Carnivore activity and movement in a Southern California protected area, the North/Central Irvine Ranch. U.S. Geological Survey Technical Report, 115 p.

Menotti-Raymond, M., David V.A., Lyons L.A., *et al.* 1999. A genetic linkage map of microsatellites in the domestic cat (*Felis catus*). Genomics 57:9-23.

Menotti-Raymond, M.A., David V.A., Wachter L.L., Butler J.M., O'Brien S.J. 2005. An STR forensic typing system for genetic individualization of domestic cat (*Felis catus*) samples. Journal of Forensic Sciences 50:1061-1070.

Miller, N. L. and N. J. Schlegel. 2006. Climate change projected fire weather sensitivity: California Santa Ana wind occurrence. Geophysical Research Letters 33.

Ogden Environmental and Energy Services. 1996. Biological Monitoring Plan for the Multiple Species Conservation Plan. San Diego, CA.

Park, S.D.E. 2001. Trypanotolerance in West African Cattle and the Population Genetic Effects of Selection [Ph.D. thesis] University of Dublin.

Pearce, J.L. and M.S. Boyce. 2006. Modelling the distribution and abundance with presence-only data. Journal of Applied Ecology 43: 405-412.

Pritchard, J.K., Stephens M., Donnelly P. 2000. Inference of population structure using multilocus genotype data. Genetics 155:945-959.

Reed, S.E. and A.M. Merenlender. 2008. Quiet, nonconsumptive recreation reduces protected area effectiveness. Conservation Letters 1(3): 1-9.

Riley, S.P.D., Pollinger, J.P., Sauvajot, R.M., York, E.C., Bromley, C., Fuller, T.K., and Wayne, R.K. 2006. A southern California freeway is a physical and social barrier to gene flow in carnivores. Molecular Ecology 15:1733-1741.

Riley, S.P.D., Bromley, C., Poppenga, R.H., Uzal, F., Whited, L., and Sauvajot, R.M. 2007. Anticoagulant exposure and notoedric mange in bobcats and mountain lions in urban southern California. Journal of Wildlife Management 71(6):1874-1884.

Riverside County. 2003. Western Riverside Multiple Species Habitat Conservation Plan Documents.

Rousset, F. 2008. GENEPOP ' 007: a complete re-implementation of the GENEPOP software for Windows and Linux. Molecular Ecology Resources 8:103-106.

Safford, H.D., K. van de Water, and D. Schmidt. 2011. California Fire Return Interval Departure (FRID) map, 2010 version. USDA Forest Service, Pacific Southwest Region and The Nature Conservancy-California. URL: http://www.fs.fed.us/r5/rsl/clearinghouse/r5gis/frid/

SanGIS/SANDAG Data Warehouse. December 2010. PlanLU. San Diego Geographic Information Source - JPA/San Diego Association of Governments (SANDAG). Downloaded May 2013. http://www.sangis.org/Download_GIS_Data.htm

Singleton P.H., W.L. Gaines, and J.F. Lehmkuhl. 2004. Landscape permeability for grizzly bear movements in Washington and southwestern British Columbia. Ursus 15: 90-103.

Soulé, M.E. 1991. Conservation: Tactics for a constant crisis. Science 253: 744-750.

Spencer, W. D., P. Beier, K. Penrod, M. Parisi, A. Pettler, K. Winters, J. Strittholt, C. Paulman, and H. Rustigian-Romsos. 2010. California Essential Habitat Connectivity Project: a strategy for conserving a connected California. Report. California Department of Transportation and California Department of Fish & Game, Sacramento, California. Available from http://www.dfg.ca.gov/habcon/connectivity/ (accessed October 2012).

Stralberg, D., Jongsomjit D., Howell C.A., Snyder M.A., Alexander J.D., *et al.* 2009. Re-Shuffling of Species with Climate Disruption: A No-Analog Future for California Birds? PLoS ONE 4(9):e6825.

Swetnam, T. W. and J. L. Betancourt. 1998. Mesoscale disturbance and ecological response to decadal climatic variability in the American Southwest. Journal of Climate 11:3128-3147.

Taylor P.D., L. Fahrig, K. Henein, G. Merriam. 1993. Connectivity is a vital element in landscape structure. Oikos 68: 571–73

Tischendorf L., and L. Fahrig. 2000a. How should we measure landscape connectivity? Landscape Ecology 15: 633–41.

Tischendorf L., and L. Fahrig. 2000b. On the usage and measurement of landscape connectivity. Oikos 90: 7–19.

Tobler, M. 2012. Camera Base 1.6. http://www.atrium-biodiversity.org/tools/camerabase/

Toonen R.J. and Hughes S. 2001. Increased Throughput for Fragment Analysis on ABI Prism 377 Automated Sequencer Using a Membrane Comb and STRand Software, Biotechniques, 31:1320-1324. http://www.vgl.ucdavis.edu/informatics/strand.php

Van Oosterhout, C., Hutchinson W.F., Wills D.P.M., Shipley P. 2004. MICRO-CHECKER: software for identifying and correcting genotyping errors in microsatellite data Molecular Ecology Notes 4:535-538.

Westerling, A. L., A. Gershunov, T. J. Brown, D. R. Cayan, and M. D. Dettinger. 2003. Climate and wildfire in the western United States. Bulletin of the American Meteorological Society 84:595-604.

FIGURES AND TABLES

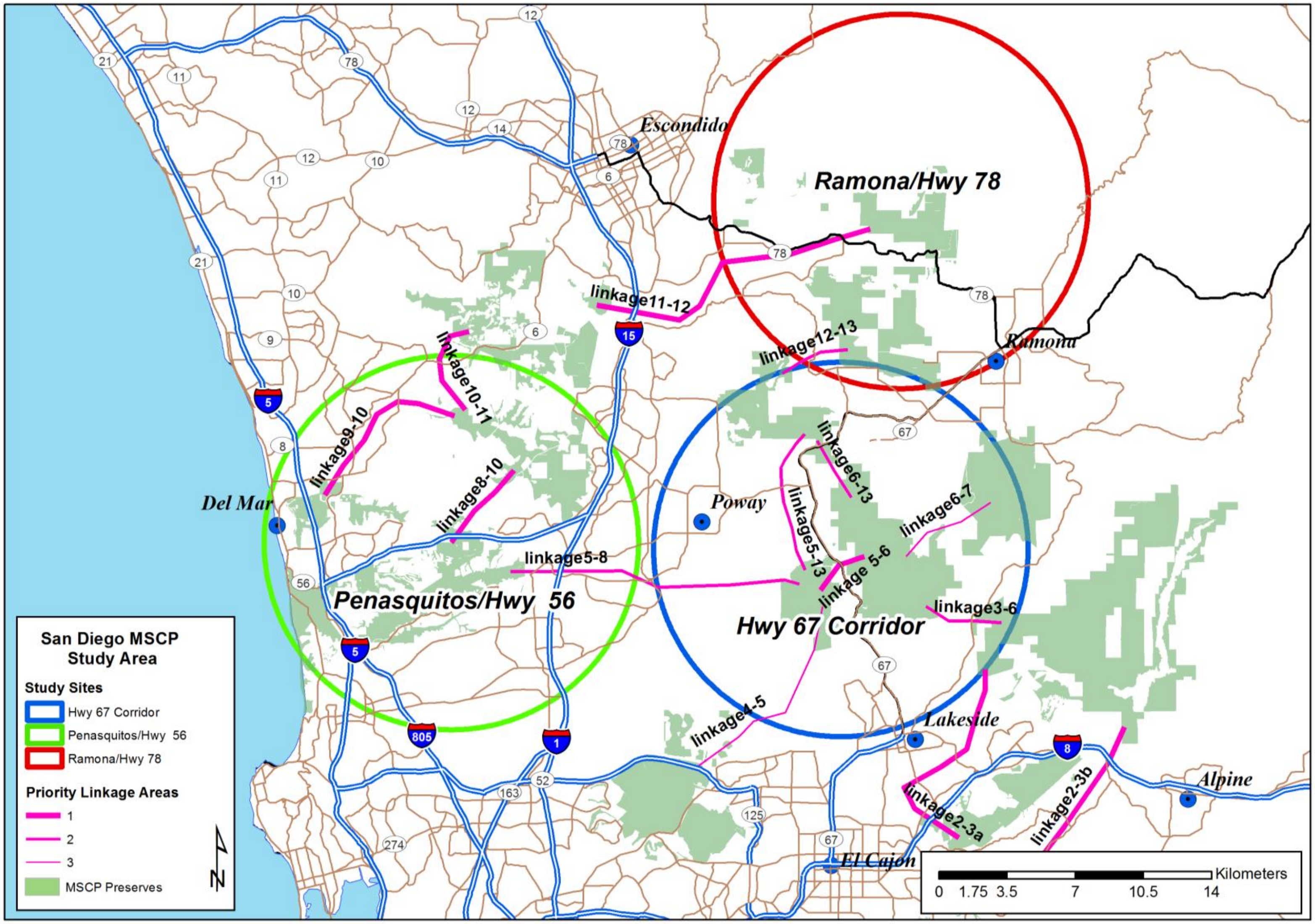

Figure 1. Map of study areas monitoring San Diego County MSCP open space network with core preserves in green. Pink lines represent putative linkage areas previously identified by the MSCP Connectivity Monitoring Strategic Plan. Large circles identify three primary study areas in coastal and inland sites along three major transportation corridors.

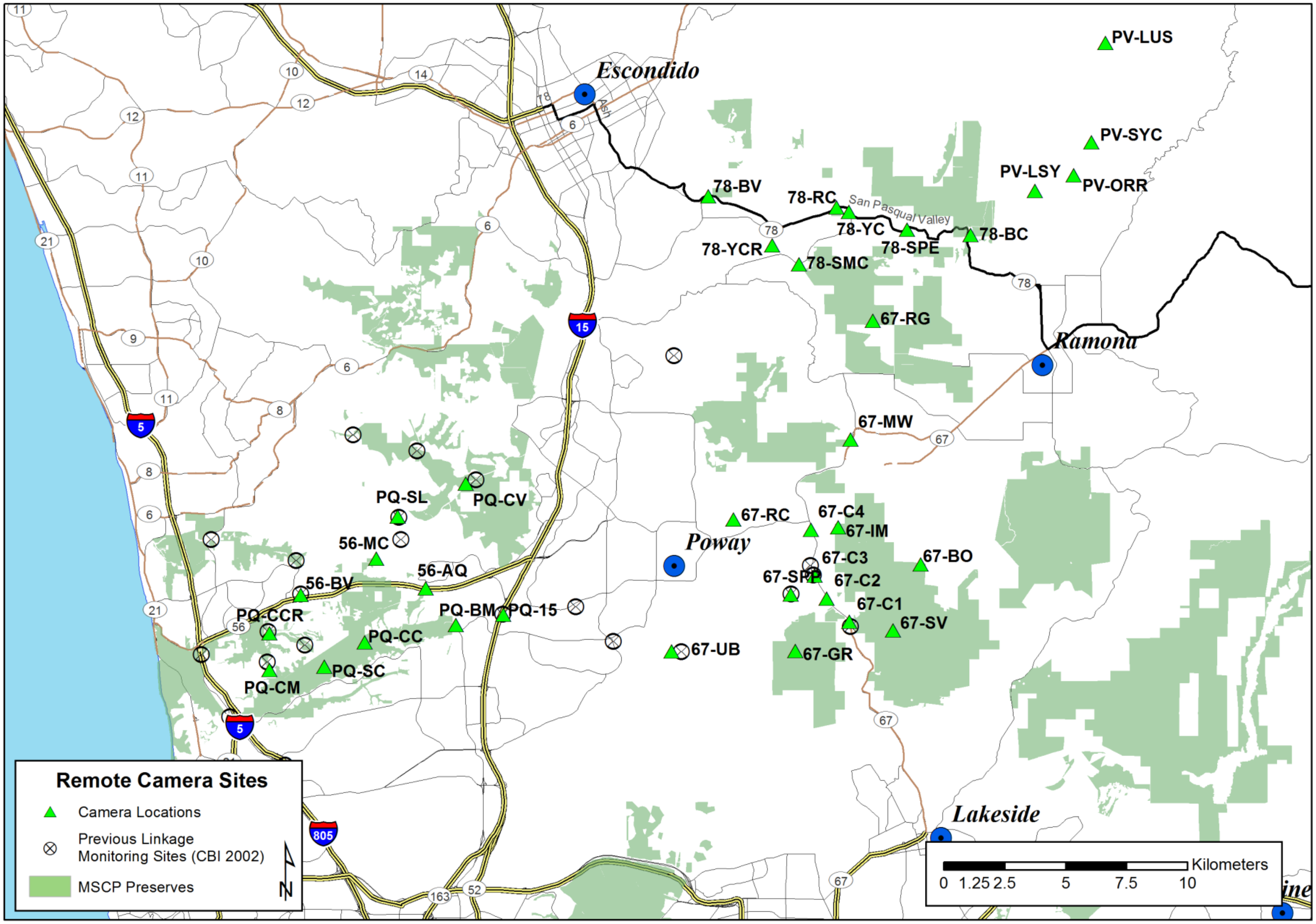

Figure 2. Map of study area with remote camera station monitoring locations (green triangular symbols) with respect to preserve lands. Recommended linkage monitoring sites previously identified (CBI 2002) are represented by circles with an X.

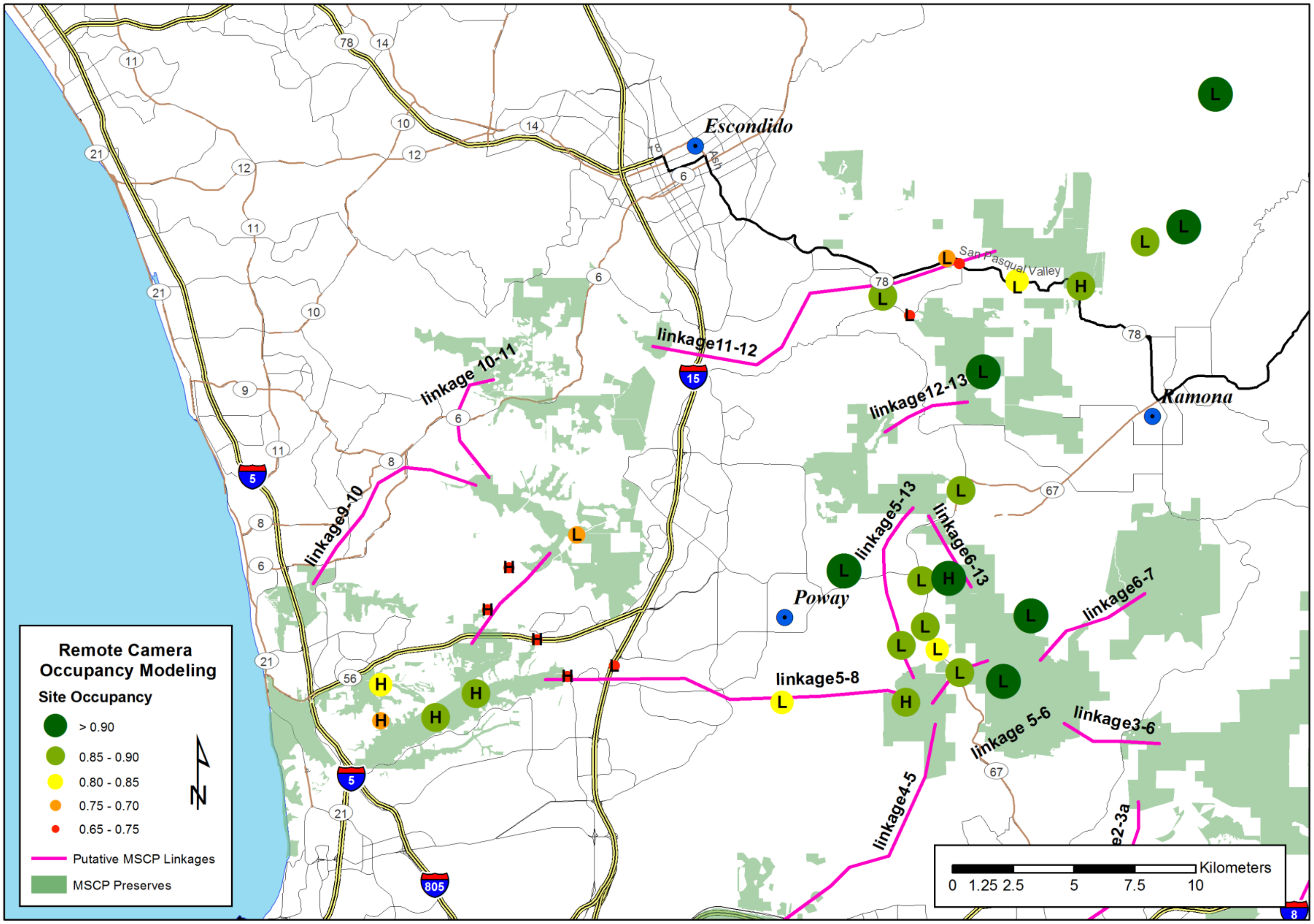

Figure 3. Map of bobcat occupancy rates at remote camera stations (n = 32) determined by occupancy modeling. Rates range from 0.66 to 0.907, represented by smaller red shades at lower occupancies to larger, green shades at the highest occupancy rates. Recreation level at each station is denoted as high (H) or low (L).

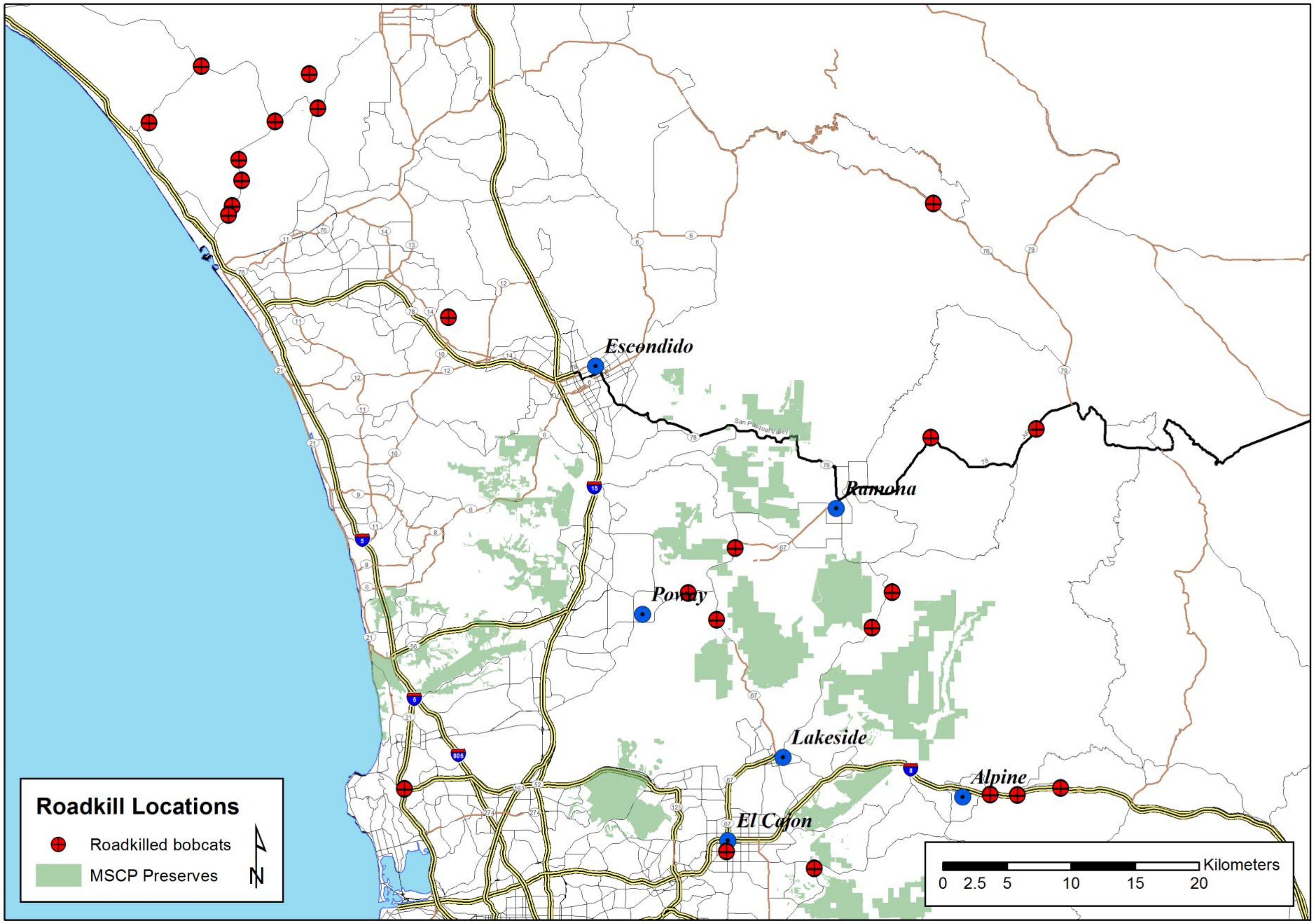

Figure 4. Locations of roadkill bobcats (n = 24) collected or recorded in San Diego County between 2010 and 2013, with the exception of one roadkill location at Marine Corps Base Camp Pendleton collected in 2007.

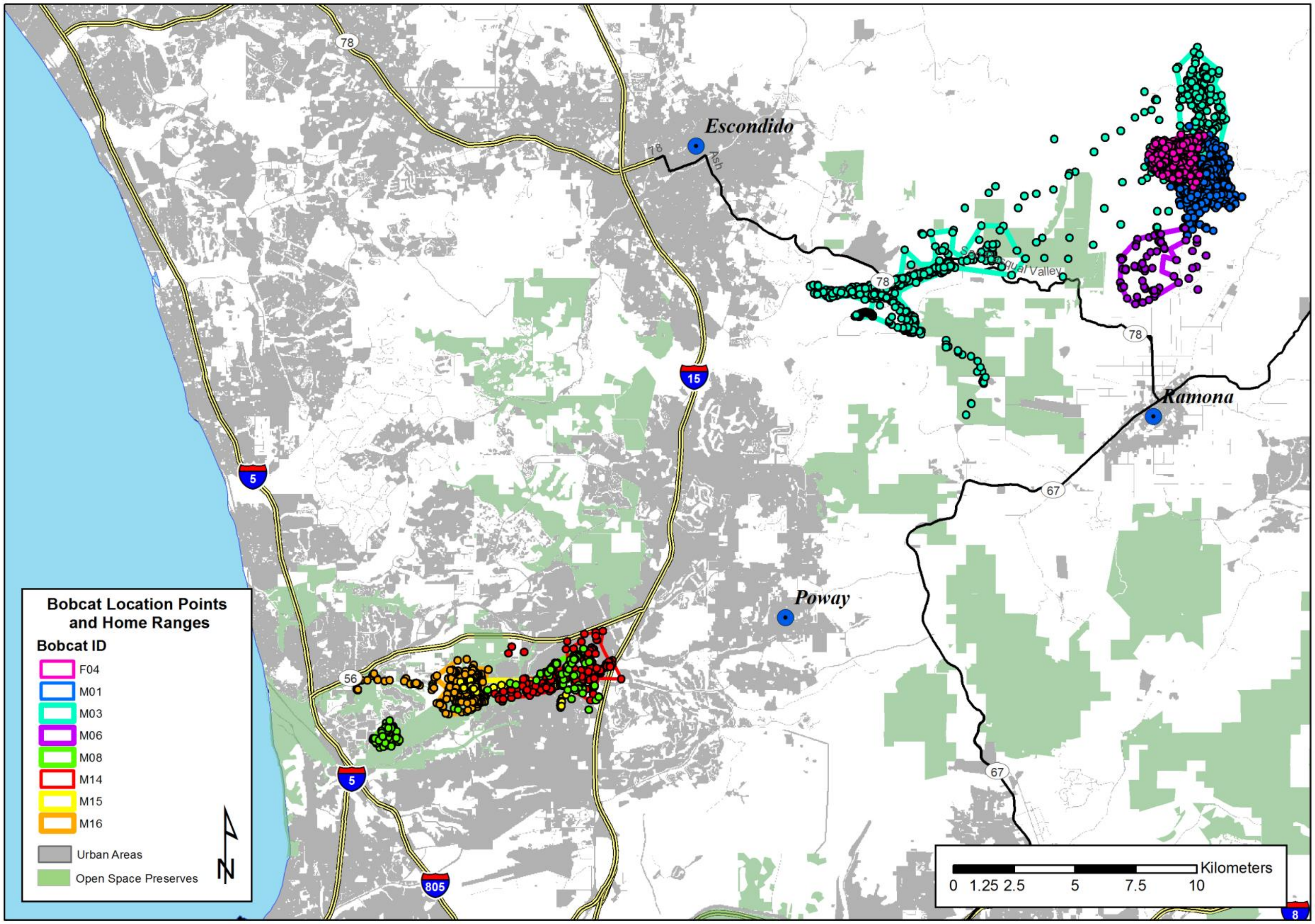

Figure 5. GPS point locations and LoCoH home range estimates for tracked bobcats. Each individual (n = 8) is represented by a different color. Locations are depicted with respect to urban areas, shaded in gray.

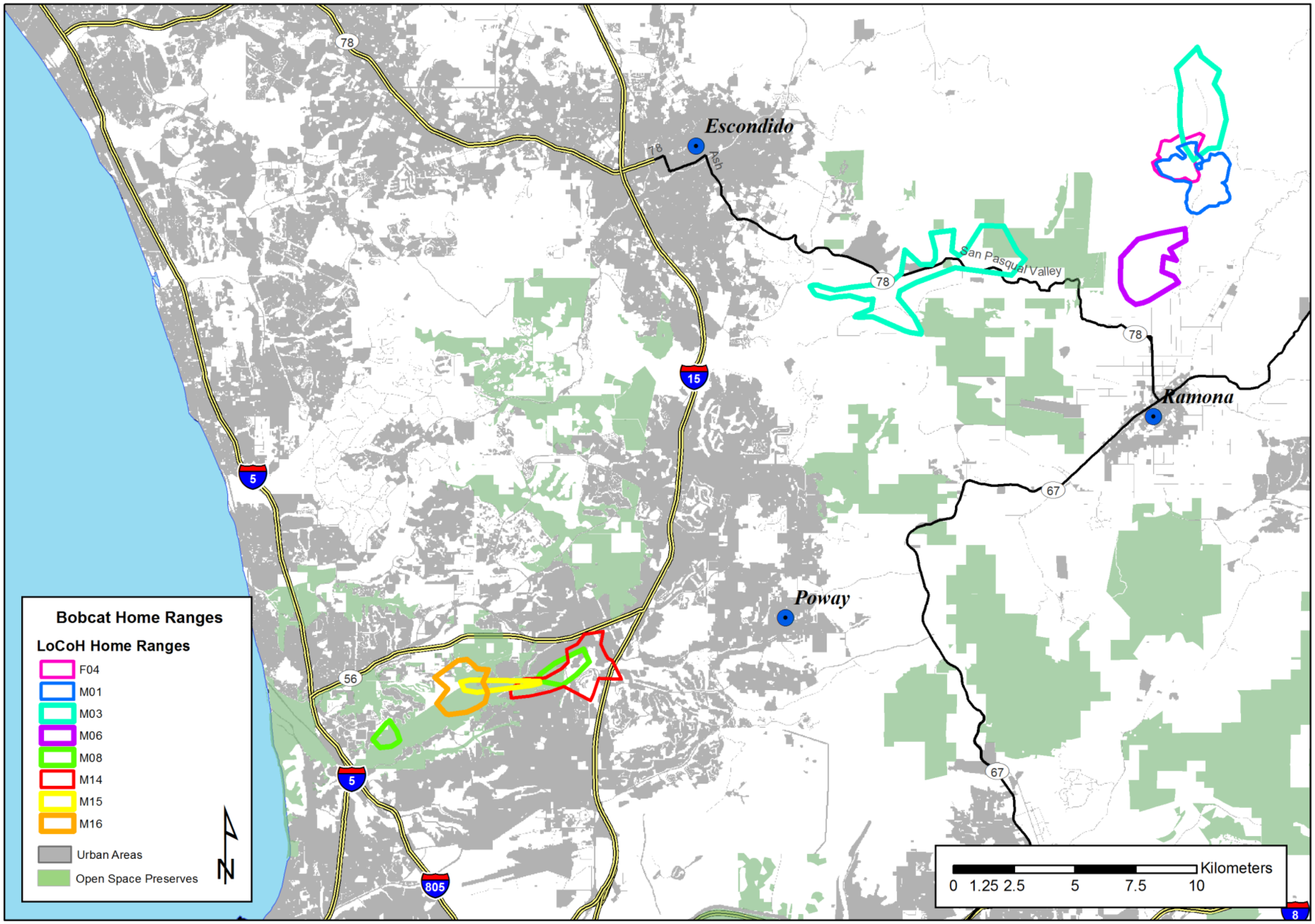

Figure 6. Local Convex Hull (LoCoH) home ranges for all bobcats with GPS collar data retrieved (n = 8). Home ranges are shown with respect to open space preserve boundaries (in green), and areas of urban development (in gray).

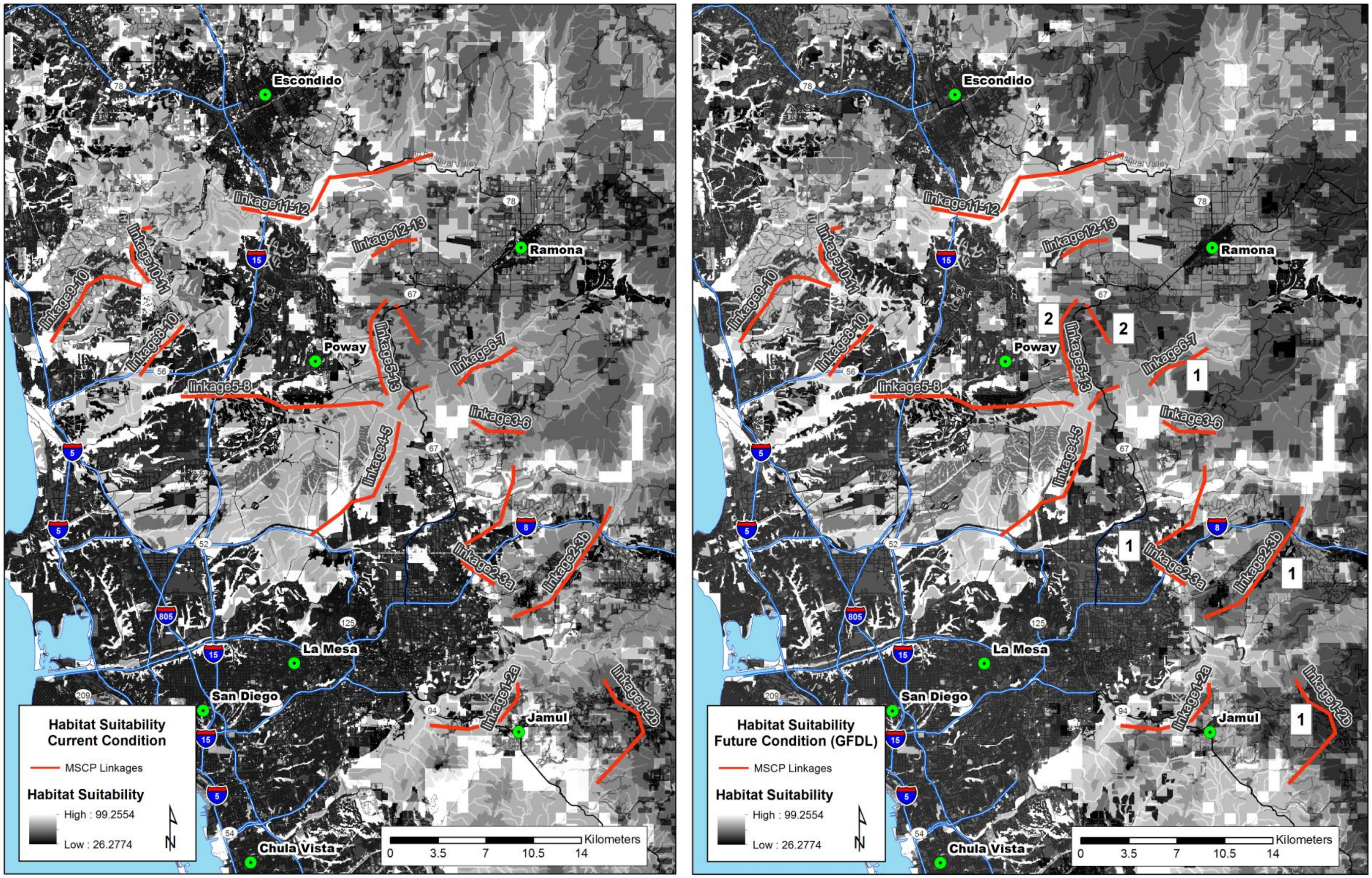

Figure 7. Habitat suitability for the MSCP area under current climate and land use conditions (left panel), and under future climate scenario GFDL and 2050 planned land use conditions (right panel). Lighter areas indicate high habitat suitability. Putative linkage areas are identified by red lines. Numbered squares in right hand panel indicate locations with decreased habitat suitability: 1) due to habitat alteration; 2) due to habitat alteration and roads.

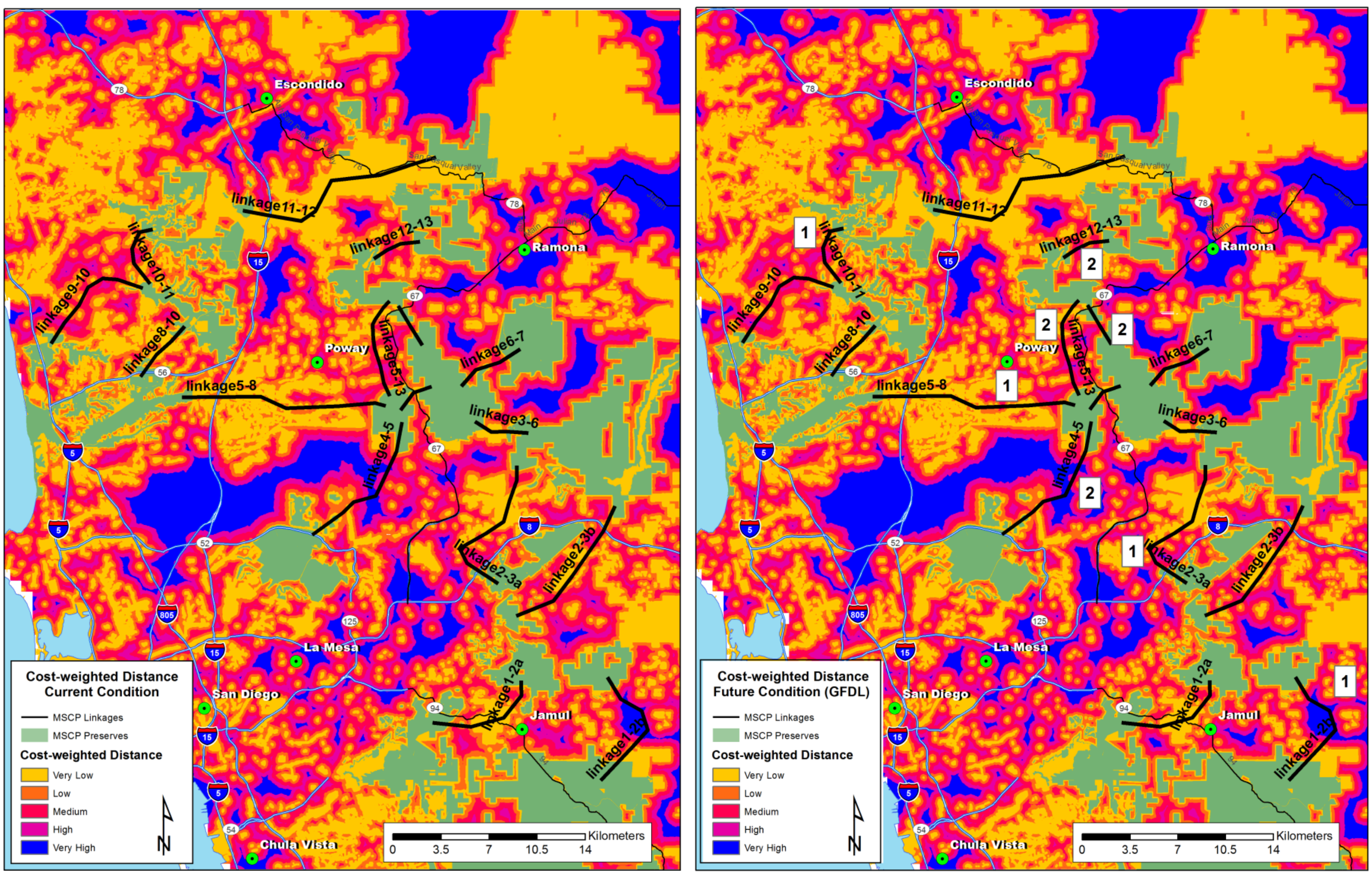

Figure 8. Landscape connectivity assessed by cost-weighted distance for the MSCP area under current climate and land use conditions (left panel), and under future climate scenario GFDL and 2050 planned land use conditions (right panel). Warmer colors indicate areas of lowest effective distance, increasing to highest distances in cooler colors. Putative linkages are identified by black lines. Numbered squares in right hand panel indicate locations with decreased connectivity: 1) due to habitat alteration/development; 2) due to habitat alteration and roads.

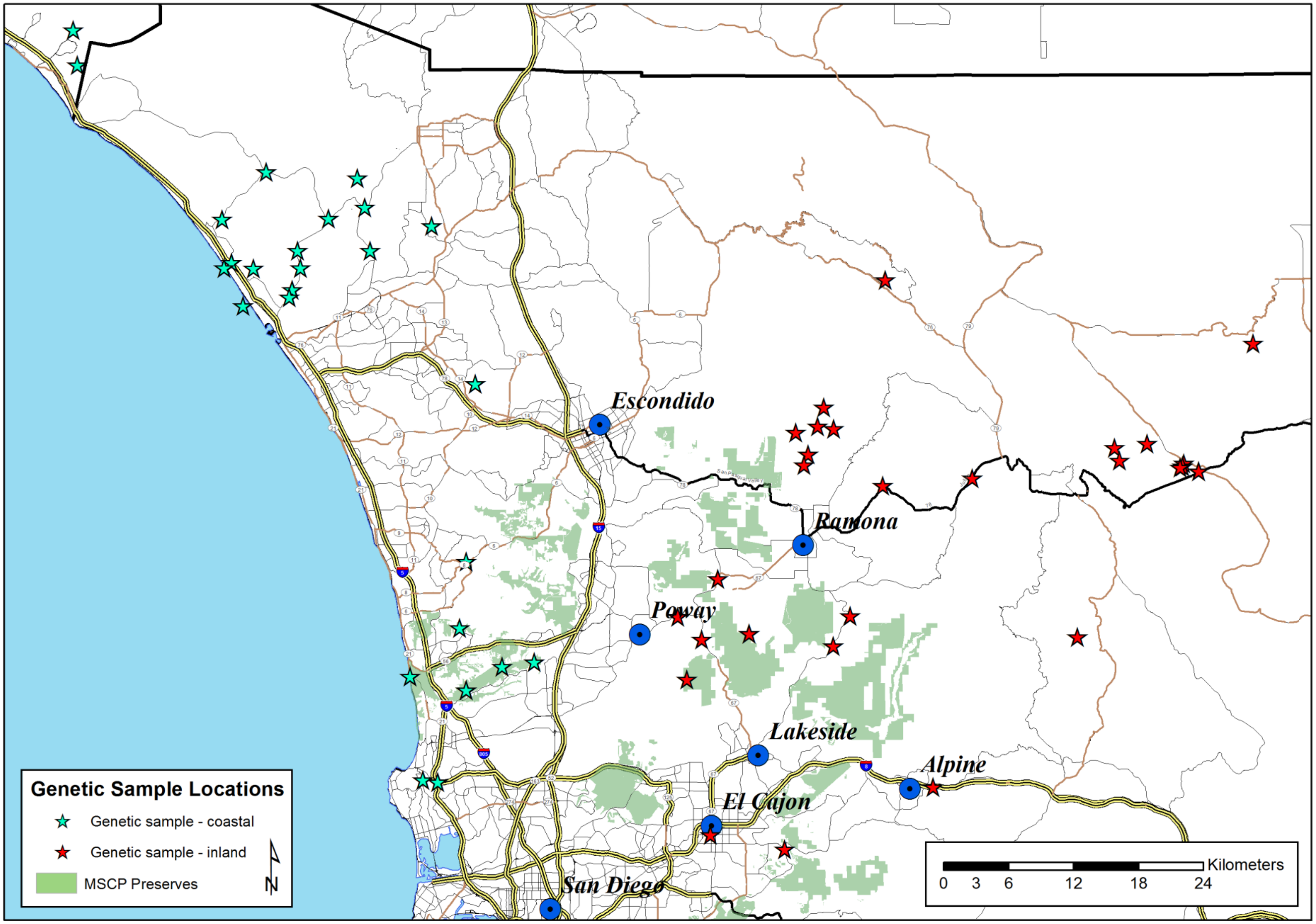

Figure 9. Map of sampling locations for genetic data analyzed (n = 62) and putative subpopulation assignment. Individuals assigned to the coastal population (west of I-15 freeway) are in turquoise, and those in the inland population (east of I-15) are in red.

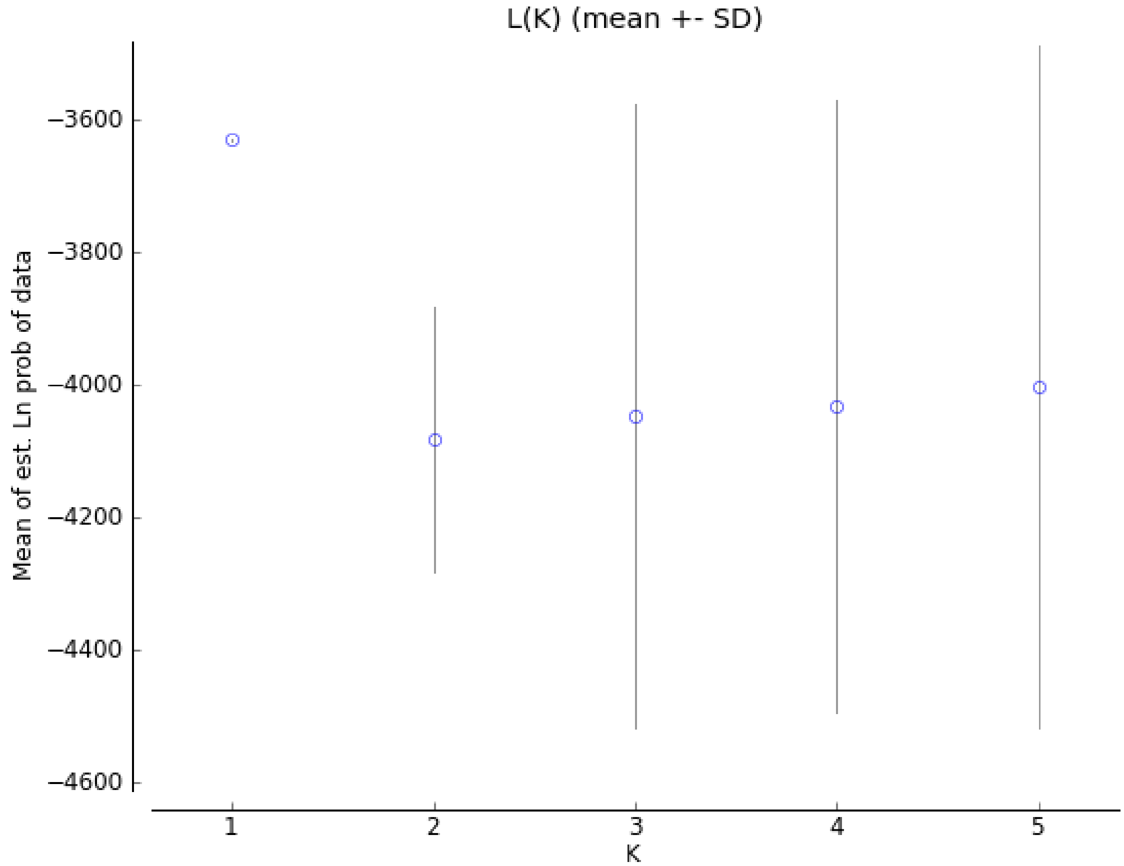

Figure 10. Mean estimated (± SE) probability of the number (K = 1 to 5) of subpopulations of bobcats supported by STRUCTURE analysis. Results support identification of one, panmictic population.

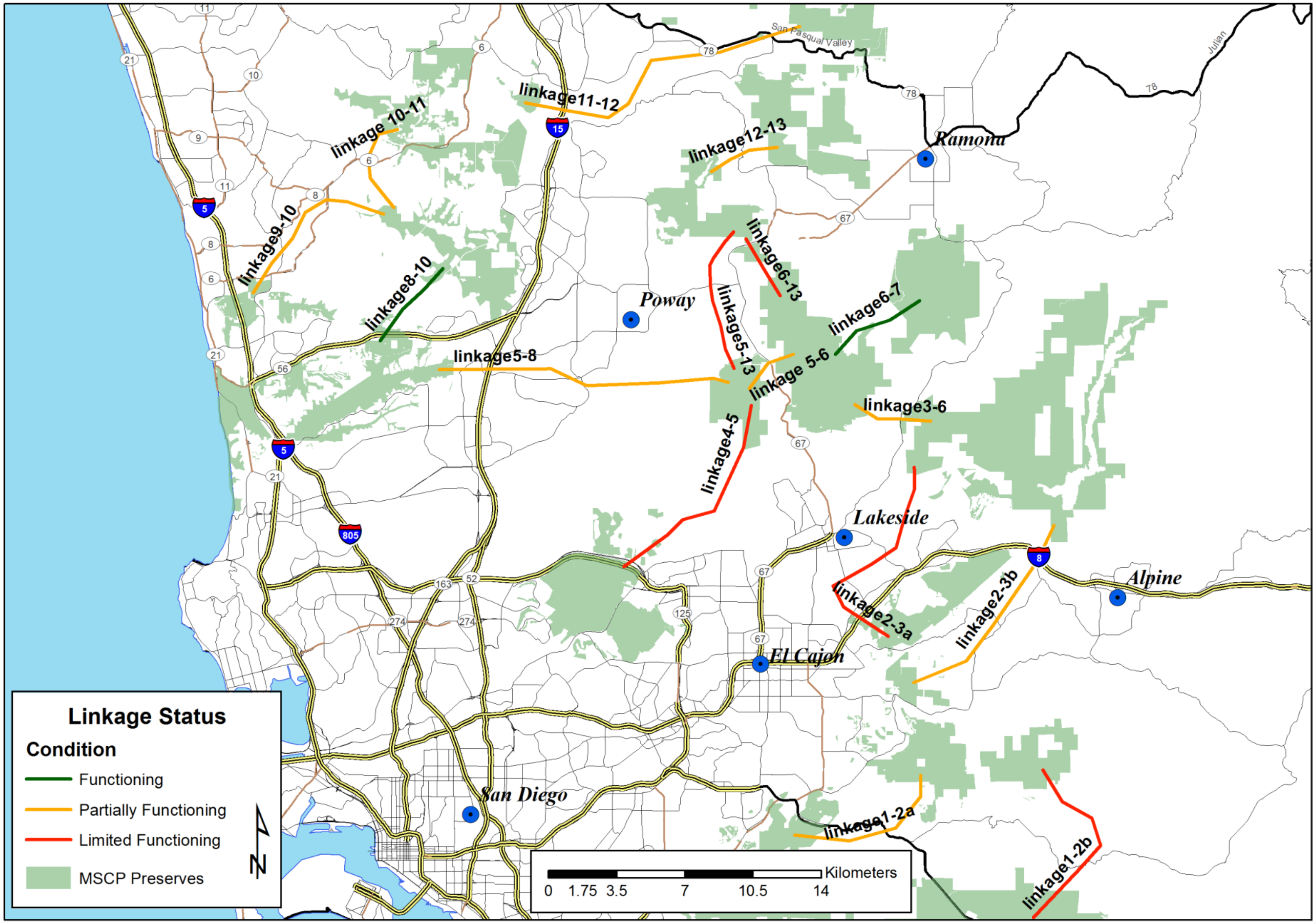

Figure 11. Linkage status map. Status was assessed based on empirical data and modeling results. Red indicates only limited linkage functioning, orange - partial functioning, and green represents functioning linkages.

Station ID	*Study Area*	*Site Type*	*Recreation*	*Camera*
56-AQ	Los Peñasquitos/SR56	Bridge	M	Cuddeback
56-BV	Los Peñasquitos/SR56	Bridge	L	Cuddeback
56-MC	Los Peñasquitos/SR56	Bridge	M	LTL Acorn
67-BO	SR67	Core	L	LTL Acorn
67-C1	SR67	Culvert	L	Cuddeback
67-C2	SR67	Culvert	L	LTL Acorn
67-C3	SR67	Culvert	L	LTL Acorn
67-C4	SR67	Culvert	L	Cuddeback
67-GR	SR67	Core	M	LTL Acorn
67-IM	SR67	Core	H	LTL Acorn
67-MW	SR67	Culvert	L	LTL Acorn
67-RC	SR67	Core	M	LTL Acorn
67-RG	SR67	Core	L	LTL Acorn
67-SPP	SR67	Tunnel	M	LTL Acorn
67-SV	SR67	Core	L	Cuddeback
67-UB	SR67	Linkage	L	LTL Acorn
78-BC	Pamo Valley/SR78	Core	M	LTL Acorn
78-BV	Pamo Valley/SR78	Bridge	L	Cuddeback
78-RC	Pamo Valley/SR78	Bridge	L	LTL Acorn
78-SMC	Pamo Valley/SR78	Bridge	L	Cuddeback
78-SPE	Pamo Valley/SR78	Tunnel	L	LTL Acorn
78-YC	Pamo Valley/SR78	Bridge	H	Cuddeback
78-YCR	Pamo Valley/SR78	Linkage	L	LTL Acorn
PQ-15	Los Peñasquitos/SR56	Bridge	M	Cuddeback
PQ-805	Los Peñasquitos/SR56	Bridge	M	Cuddeback
PQ-BM	Los Peñasquitos/SR56	Bridge	H	LTL Acorn
PQ-CC	Los Peñasquitos/SR56	Core	H	Cuddeback
PQ-CCR	Los Peñasquitos/SR56	Tunnel	H	LTL Acorn
PQ-CM	Los Peñasquitos/SR56	Bridge	M	LTL Acorn
PQ-CV	Los Peñasquitos/SR56	Bridge	L	LTL Acorn
PQ-SC	Los Peñasquitos/SR56	Core	H	Cuddeback
PQ-SL	Los Peñasquitos/SR56	Bridge	H	Cuddeback
PV-LSY	Pamo Valley/SR78	Core	M	LTL Acorn
PV-LUS	Pamo Valley/SR78	Core	L	LTL Acorn
PV-ORR	Pamo Valley/SR78	Core	L	Cuddeback
PV-SYC	Pamo Valley/SR78	Core	L	Cuddeback

Table 1. Remote camera location identifiers and designation by study area, site type, recreation level, and camera type.

Primer	*Species*	*Repeat*	*Size range*	*Number of alleles*	*Ho*	*He*	*PIC*	*Reference*
BCD8T	Bobcat	tetra	156-180	5	0.26	0.35	0.33	1
BCE5T	Bobcat	tetra	256-280	6	0.77	0.71	0.66	1
BCG8T	Bobcat	di	275-299	12	0.89	0.85	0.83	1
FCA126	Domestic cat	di	132-154	7	0.70	0.80	0.76	2
FCA132	Domestic cat	di	182-194	7	0.79	0.83	0.80	2
FCA149	Domestic cat	di	133-149	8	0.74	0.77	0.73	2
FCA23	Domestic cat	di	144-158	6	0.79	0.73	0.69	2
FCA26	Domestic cat	di	138-166	13	0.82	0.87	0.84	2
FCA31	Domestic cat	di	237-255	9	0.79	0.87	0.84	2
FCA35	Domestic cat	di	120-150	16	0.80	0.91	0.89	2
FCA391	Domestic cat	tetra	210-236	5	0.55	0.67	0.61	2
FCA43	Domestic cat	di	131-139	5	0.74	0.74	0.69	2
FCA45	Domestic cat	di	147-173	7	0.65	0.83	0.79	2
FCA559	Domestic cat	tetra	115-135	5	0.70	0.64	0.57	2
FCA742	Domestic cat	tetra	104-134	5	0.62	0.71	0.65	3
FCA77	Domestic cat	di	130-140	8	0.63	0.73	0.69	2
FCA8	Domestic cat	di	140-156	9	0.81	0.74	0.71	2
FCA82	Domestic cat	di	246-266	10	0.90	0.85	0.83	2
FCA90	Domestic cat	di	108-126	7	0.66	0.77	0.73	2
FCA96	Domestic cat	di	189-209	10	0.71	0.84	0.82	2
Lc110	Lynx	di	92-104	7	0.51	0.60	0.55	4
Lc111	Lynx	di	157-217	7	0.79	0.76	0.72	4

Table 2. Locus name, species developed from, repeat motif of microsatellite markers used in genetic analysis. Size range, number of alleles, expected and observed heterozygosity and PIC were based on analysis of 62 bobcat samples. Reference indicates initial publication of markers by: 1. Faircloth *et al.* 2005; 2. Menotti-Raymond *et al.* 1999; 3. Menotti-Raymond *et al.* 2005; Carmichael *et al.* 2000.

Individual	*Capture Date*	*Status*	*Location*	*Comments*
M01	5/13/2009	Collared	Pamo Valley	
M02	1/2/2010	Collared	Pamo Valley	Collar not retrieved
M03	8/22/2010	Collared	Pamo Valley	
F04	9/23/2010	Collared	Pamo Valley	Mortality – suspected puma
F05	10/13/2010	Collared	Pamo Valley	Collar failure
M06	11/9/2010	Collared	Pamo Valley	
M07	10/15/2011	Collared	Los Peñasquitos	Collar not retrieved
M08	10/27/2011	Collared	Los Peñasquitos	Mortality – suspected coyote or domestic dog
M09	10/29/2011	Collared	Los Peñasquitos	Collar not retrieved
M10*	11/29/2011	Collared	FFAWC rehab release – Black Mtn.	Animal missing
F11*	11/22/2011	Ear tagged	FFAWC rehab release - Tenaja	
M12*	11/29/2011	Collared	FFAWC rehab release – Los Peñasquitos	Attempting to recapture
F13*	11/22/2011	Ear tagged	FFAWC rehab release – Torrey Pines	
M14	1/1/2012	Collared	Los Peñasquitos	
M15	1/7/2012	Collared	Los Peñasquitos	
M16	1/8/2012	Collared	Los Peñasquitos	
M17	2/4/2012	Collared	Goodan Ranch	Collar being inspected for data retrieval
F18	2/12/2012	Collared	Boulder Oaks Preserve	Animal missing
M20	3/3/2012	Collared	Boulder Oaks Preserve	Rehabbed for mange first; Attempting recapture

Table 3. Data for all bobcats sampled (n = 19), including individual identifier, date of capture or processing*, tracking status (collar or ear tag only), location of capture, and notes on animal or collar fate. *Four animals were rehabilitated animals from the Fund for Animals Wildlife Center in Ramona. Only two of those animals were collared prior to release back into the wild.

Animal	Urban	Altered	Natural	HR Area (km^2)
M01	1%	8%	92%	4.79
M03a	5%	42%	54%	10.12
M03b	1%	31%	68%	6.37
F04	1%	1%	98%	2.79
M06	0%	9%	91%	5.13
M08a	3%	0%	97%	0.72
M08b	31%	7%	61%	1.55
M14	40%	5%	55%	5.26
M15	14%	0%	86%	1.05
M16	8%	0%	92%	3.43

Table 4. LoCoH home range information for each bobcat with GPS collar data available. Data include total home range area (km^2) and percentage of home range in land use categories urban, altered, and natural.

Variable	***Coefficient***	***SE***	***p-value***
Fire			
Fire return interval departure (6 classes)			
-999	1.323	0.837	0.114
-3	0.518	0.838	0.537
-2	0.529	0.837	0.528
-1	1.598	0.84	0.057
1	0.987	0.841	0.241
2	1.608	0.84	0.056
Habitat			
Herbaceous	0.492	0.057	0
Shrubland	-0.521	0.039	0
Hardwood	0.656	0.067	0
Agricultural	0.089	0.087	0.307
Urban	-0.205	0.077	0.008
Water/Wetland	3.188	0.397	0
Distance to water/100	-0.237	0.013	0
Land Use			
Urban (LU URB)	-1.179	0.119	0
Altered	0.137	0.062	0.027
Natural	0.186	0.055	0.001
Distance to local road/100	-0.042	0.005	0
Distance to major road/100	0.004	0.001	0
Topography			
Elevation/100	-0.322	0.015	0

Table 5. Univariate logistic regression results for each model variable from bobcat telemetry point modeling.

Model	*AIC_c*	*ΔAIC*	*$AICw_i$*
All Habitat, All Land Use, and Topography (HERB + HDW + WAT + SHB + URB + DIST WAT + LU URB + MAJRD + LOCRD + ELEV)	**15520.22**	**0**	**>0.999**
Avoided Land Use and Topography (LU URB + ELEV)	15672.69	152	<0.001
All Habitat, Avoided Land Use and Topography (HERB + HDW + WAT + SHB + URB + DIST WAT + LU URB + ELEV)	15995.97	476	<0.001
All Habitat and Topography (HERB + HDW + WAT + SHB + URB + DIST WAT + ELEV)	16114.3	594	<0.001
Topography (ELEV)	16316	796	<0.001
All Habitat and All Land Use (HERB + HDW + WAT + SHB + URB + DIST WAT + LU URB + NAT + MAJRD + LOCRD)	16517.46	997	<0.001
All Vegetation and Water (HERB + HDW + WAT + SHB + URB + DIST WAT)	16621.26	1101	<0.001
All Vegetation (HERB + HDW + WAT + SHB + URB)	16863.75	1344	<0.001
Avoided Vegetation (SHB + URB)	17013.01	1493	<0.001
Selected Vegetation (HERB + HDW + WAT)	17044.07	1524	<0.001
Avoided Land Use and Roads (URB + MAJRD + LOCRD)	17127.4	1607	<0.001
All Land Use and Roads (LU URB + NAT + MAJRD + LOCRD)	17128.84	1609	<0.001
All Land Use (URB + NAT)	17263.78	1744	<0.001
Avoided Land Use (LU URB)	17265.31	1745	<0.001
Selected Land Use (NAT)	17370.26	1850	<0.001

Table 6. Models of bobcat presence with regard to landscape variables, ranked by Akaike's information criteria for small samples (AIC_c) with ΔAIC, and model weights $AICw_i$. Variables for each model can be found in Table 5. Bold indicates model with greatest support.

Effect	*Coefficient*	*Odds ratio*	*95% confidence limit odds ratio*	
Intercept	1.391			
HERB	-0.334	0.716	0.503	1.018
HDW	-0.001	0.999	0.850	1.174
WAT	**2.031**	**7.624**	**2.947**	**19.719**
SHB	**-0.566**	**0.568**	**0.335**	**0.963**
URB	0.064	1.066	0.385	2.951
DISTWAT	-0.062	0.940	0.788	1.120
LU_URB	**-1.323**	**0.266**	**0.160**	**0.444**
LOCRD	**0.073**	**1.076**	**1.013**	**1.144**
MAJRD	**0.034**	**1.035**	**1.018**	**1.051**
ELEV	**-0.921**	**0.398**	**0.281**	**0.565**

Table 7. Beta coefficients, odds ratios, and 95% confidence limits for odds ratios for variables in the final selected GLMM. Bold indicates variables with the greatest influence on predictions of bobcat presence.

Land Cover		***Elevation***		***Distance to Road***		***Distance to Water***		***Habitat***	
Class	*Score*	*Class*	*Score*	*Class*	*Score*	*Class*	*Score*	*Class*	*Score*
Urban	20	<200 m	100	20 m	20	20 m	100	Wetland	100
Altered	50	200 - 400 m	80	40 m	40	40 m	80	Altered	50
Natural	100	400 - 600 m	50	> 40 m	100	60 m	60	Grassland	60
Water	80	> 600 m	30			>60m	40	Riparian	60
								Shrub	30
								Forest	50
								Other	40
Weight	0.3		0.2		0.1		0.1		0.3

Table 8. Assigned habitat suitability values based on empirical results from univariate and GLMM modeling of bobcat habitat selection. Bottom row indicates weight assigned to each variable type, based on strength of response in models.

Name	Condition	Primary Concerns	Data Used for Assessment
Linkage 6-7	Functioning	Future habitat alteration	Cameras, Habitat suitability and connectivity modeling
Linkage 8-10	Functioning		Cameras, Telemetry, Habitat suitability and connectivity modeling
Linkage 1-2a	Partially Functioning	Road crossing and altered habitat	Habitat suitability and connectivity modeling
Linkage 2-3b	Partially Functioning	Road crossing and altered habitat	Habitat suitability and connectivity modeling
Linkage 5-6	Partially Functioning	Road crossing and altered habitat	Cameras, Roadkill, Habitat suitability and connectivity models
Linkage 5-8	Partially Functioning	Development/altered habitat, secondary roads, total distance	Cameras, Telemetry, Habitat suitability and connectivity modeling
Linkage 9-10	Partially Functioning	Development/altered habitat, secondary roads	Habitat suitability and connectivity modeling
Linkage 10-11	Partially Functioning	Development/altered habitat, secondary roads	Habitat suitability and connectivity modeling
Linkage 11-12	Partially Functioning	Road crossing and altered habitat	Cameras, Telemetry, Habitat suitability and connectivity modeling
Linkage 12-13	Partially Functioning	Development/altered habitat, secondary roads	Habitat suitability and connectivity modeling
Linkage 3-6	Partially Functioning	Secondary roads	Roadkill, Habitat suitability and connectivity modeling
Linkage 1-2b	Limited Functioning	Road crossing and altered habitat	Habitat suitability and connectivity modeling
Linkage 2-3a	Limited Functioning	Road crossing and altered habitat	Habitat suitability and connectivity modeling
Linkage 4-5	Limited Functioning	Development/altered habitat, secondary roads, total distance	Habitat suitability and connectivity modeling
Linkage 6-13	Limited Functioning	Road crossing and altered habitat	Cameras, Habitat suitability and connectivity modeling
Linkage 5-13	Limited Functioning	Development/altered habitat, secondary roads	Cameras, Roadkill, Habitat suitability and connectivity modeling

Table 9. Assessment of linkage status across the MSCP preserve network, with primary concerns for connectivity.

APPENDIX A: HABITAT MODELING METHODOLOGY

For the habitat models developed from bobcat GPS collar data, we identified the proportional area of each of these types within a 30 meter buffer around each location point. We also calculated a distance to water variable (DIST WAT), measuring the Euclidian distance to blue line streams from the USGS National Hydrology Dataset stream layer. Land-use variables were developed from the Southern California Association of Government's (SCAG) land-use data layers, which were categorized into four groups of urban (URB), altered (LU ALT), natural (NAT) and water (LU WAT) and calculated as the proportional area within 30 meters of each point. Euclidian distances from major (DIST MAJRD) and local roads (DIST LOCRD) were also incorporated into the models, and were developed from the CalTrans TIGER data. Topographic data consisted of elevation data (ELEV) from digital elevation models. To assist in interpretation of model results, the distances to water, major and minor roads, and elevation were scaled by dividing each value by 100 m. The fire-return interval departure data is a measure of the shifting fire regime (meanCC FRI), which is a categorical variable with seven classes representing the condition class, or the degree of departure from the natural fire regime with respect to the fire-return interval (Hann and Bunnell 2001, Safford *et al.* 2011). For this last variable, increasingly negative values (-1 to -3) equate to areas that have burned more frequently than the natural fire-return interval (FRI) and are at increasing risk of type conversion. Increasing positive values (1 to 3) reflect areas that have not burned as often as expected when compared to historic FRI. The remaining category represents urban or altered areas that do not have the vegetative structure to carry fire and therefore, do not have a condition class or FRI.

We ran binary generalized-linear-mixed models (GLMM) of bobcat presences and pseudoabsences (Pearce and Boyce 2006, Aarts *et al.* 2012) using the PROC GLIMMIX function in SAS. GLMMs are a robust tool to analyze habitat-selection with telemetry data because the random effects resulting from serial correlation in location data from each individual can be estimated to allow for more accurate and appropriate analysis of population-level effects (Gillies *et al.* 2006, Bolker *et al.* 2009, Burdett 2010). To create binary data, we generated pseudoabsences in proportion to the number of presences for each individual within the 100% MCP using the Geospatial Modelling Environment command to generate stratified random points (Beyer 2012). All variables were first tested using binary logistic regression to determine which were significant on their own and whether the response to each indicated selection or avoidance, which was then factored into GLMM development. Models calculated random effects with the random intercept method with an autoregressive covariance structure and the Huber-White Sandwich variance estimator to calculate empirical standard errors that are robust to the lack of independence in the telemetry data due to both the spatial autocorrelation of locations and correlation of points from each bobcat (Clark and Stevens 2008). GLMMs were fit using the random intercept method and Laplace likelihood approximation, which is a less biased method for fitting GLMMs than pseudo-likelihoods (Bolker *et al.* 2009). We created a correlation matrix of predictor variables with Spearman rank coefficients to determine which variables were correlated at $r > |0.6|$ and these variables were run separately to avoid multicollinearity.

We took a stepwise approach to determine which variables in the GLMM model best explained bobcat response to landscape features. In this stepwise approach, all significant, uncorrelated variables were entered into the model according to the variable categories described above (vegetation, land-use, terrain, and fire). We based model selection on an information theoretic approach using the small sample correction of Akaike's Information Criteria (AIC_c)

and compared overall differences between models with ΔAIC to determine which model best fit the data. We also calculated model weights, AICw_i, or the likelihood of a model, according to Burnham and Anderson (2002). To better understand which variables in the best models were influencing patterns of bobcat presence, we recorded the odds ratios for each variable, as well as the 95% confidence limits for those odds ratios. Odds ratios with confidence limits that bound one are considered less influential in the model.

Appendix B: Habitat Suitability and Connectivity Modeling Methodology

The development of bobcat habitat suitability models and the cost-weighted connectivity assessment were based on the empirical data from our habitat use modeling and developed using raster datasets in GIS. To ensure model comparability, we determined which environmental rasters to use based on whether it included one or more variables that contributed to a significant improvement in predicting bobcat presence in the selected GLMM. For bobcats, habitat suitability was based on values assigned to rasters of habitat type, land-use, Euclidian distance from roads and water, and elevation. After assigning habitat suitability values within each category, we then needed to combine all rasters into a single landscape permeability raster by using the weighted geometric mean, which is recommended over the arithmetic mean (Beier *et al.* 2011). We weighted each raster type according to the relative influence in the models, so that the total of the weights for all rasters would equal 1.0. Habitat suitability was assessed at a 30-m pixel scale and clipped to the region where we had collected telemetry locations for bobcats.

After calculating habitat suitability, which is assumed to represent permeability of the landscape, we then used the inverse of this value to reflect landscape resistance (Singleton *et al.* 2002). Given that 100 was the maximum habitat suitability value, we subtracted the calculated habitat suitability value of each pixel from this maximum to get the complement, resistance. This resistance layer was then used as the cost value to assess the effective distance for each species to move between protected lands using the cost-weighted distance tool from the GIS Spatial Analyst toolbox. Because bobcat movement in this region is likely concentrated between areas of protected, natural lands, we used a state-wide database of conserved lands, California Protected Areas Database (CPAD 1.8, 2012) as the source features between which we calculated the cost-weighted distance. The output of this analysis represents the effective distance, or lowest cost of traveling between source locations, or in this case, protected lands.

APPENDIX C: OCCUPANCY MODEL SELECTION AND RESULTS

To eliminate modeling issues associated with missing data values, the camera sampling period analyzed in Program PRESENCE (Hines 2010) included 18 of the sampling periods, ranging from January 11, 2012 to September 19, 2012. To determine the effects of survey covariates on detection of bobcats, we first ran models with no covariates and tested for the effect of camera type and wet/dry season on probability of detection and determined that only cameras (estimate ± SE; 1.308 ± 0.229) appeared to be an important covariate for detection probability, with a lower detection probability resulting from the use of the older Cuddeback Expert model cameras, which reduced detection rates by approximately half (0.3509 compared to 0.6667). For all subsequent occupancy models, we used this detection model. We ran numerous models of occupancy testing for the effects of site type (core, bridge, culvert, or any linkage), recreation (low and high), land use, habitat type, elevation, distance to major and local roads, and distance to water on bobcat occupancy across all stations. No single model outperformed the others, and therefore, the top seven ranked models were averaged (Table C1). From our modeling efforts, several important covariates emerged for predicting bobcat occupancy at camera stations: lower occupancy rates at stations placed at bridge crossings (-2.193 ± 1.240), lower rates at stations with a greater proportion of altered habitat (-1.759 ± 1.150), and lower occupancy at stations within putative linkage zones (-1.38 ± 1.220), compared with core conserved lands. Although two other variables were identified in the top-ranked occupancy models, neither was significant. These covariates were high recreation (-0.576 ± 1.08) with lower occupancy at high recreation stations, and elevation (0.005 ± 0.010) with higher occupancy rates at the higher elevation stations in the inland study area.

Model	***AIC***	***ΔAIC***	***AICw***	***Model likelihood***	***Parameters***
Psi (bridge) , p (camera)	538.04	0.00	0.3203	1.0000	4
Psi (altered habitat), p (camera)	539.55	1.51	0.1505	0.4700	4
Psi (bridge+altered habitat), p (camera)	539.71	1.67	0.1390	0.4339	5
Psi (.), p (camera)	539.77	1.73	0.1348	0.4211	3
Psi (linkage area), p (camera)	540.29	2.25	0.1040	0.3247	4
Psi (elevation), p (camera)	540.49	2.45	0.0941	0.2938	4
Psi (high recreation), p (camera)	541.48	3.44	0.0573	0.1791	4
Psi (.), p (.)	572.51	34.47	0.0000	0.0000	2

Table C1. Top occupancy models ranked by Akaike's information criteria with ΔAIC, and model weights AICw_i. As no model clearly outperformed the others, all models were included in model averaging of occupancy rates for each camera station. Covariates included were used to model detection rates (p), and occupancy rates (Psi).