Mountain Lion *(Puma concolor)* Connectivity in the North San Diego County Multi-Species Conservation Plan Area, and

Assessment of Mountain Lion Habitat Use and Connectivity in Northern San Diego and Southern Riverside and Orange Counties, with Special Focus on Prioritization of North San Diego County MSCP Lands for Conservation, and Identification of Critical Highway Barriers and Solutions

A joint report to the San Diego County Association of Governments and California Department of Wildlife

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M86 – the only mountain lion known to have crossed I-15 from the east into the Santa Ana Mountains 2001-2016 and successfully reproduced

F92 – daughter of M86, and offspring F126 and F127, both daughters and granddaughers of M86

EXECUTIVE SUMMARY

Mountain lions (*Puma concolor*, puma, cougars) are top carnivores and important ecological regulators that roam widely throughout the San Diego County landscape. *Puma concolor* is a named species in regional conservation plans. Because of the extensive areas required by each mountain lion, multiple Natural Conservation Community Planning (NCCP) areas are often utilized by a single individual. Thus, connectivity within and between NCCPs is important for long-term health and persistence of mountain lions in the landscape, and proper NCCP function. In addition to the currently approved NCCP areas in Southern California, San Diego County is in advanced stages of preparing a conservation preserve design for its North County Multiple Species Conservation Program (NCMSCP). This research project uniquely combined camera, GPS-collar, and mortality data with state of the art genetic analyses and modeling, and an expert workshop, to produce the most comprehensive assessment to date of mountain lion habitat use and connectivity within, and adjacent to, the NCMSCP area.

The UC Davis Wildlife Health Center, along with numerous collaborators from a wide array of agencies and institutions, have been studying mountain lions in San Diego County and the surrounding region since 2001. Our previous research and that of others has shown that mountain lions are threatened by genetic isolation, roads, further habitat loss and fragmentation, and inadequate livestock husbandry practices that lead to loss of mountain lions from depredation permits or illegal shootings.

This study uniquely combined camera, GPS location, and mortality data from mountain lions in the region, with state of the art genetic analyses, advanced habitat and movement modeling, and expert opinion to provide as complete an assessment as has been done to date of the factors that affect mountain lion persistence in the NCMSCP and surrounding NCCP areas. The research team's focus was to provide key information about mountain lion movement and wildlife connectivity that is currently lacking at puma-specific scales in the NCMSCP and adjacent NCCP areas in order to assist in prioritization of habitat for conservation of this species and others. The team also focused on informing highway planners about best locations for wildlife crossing improvements for highways in the area.

The research team that conducted this study was led by researchers from U.C. Davis (Dr.'s Winston Vickers and Walter Boyce), the University of Wyoming (Dr.'s Holly Ernest and Kyle Gustafson), and the University of Massachusetts (Dr. Kathy Zeller), with collaboration on connectivity across I-15 from Trish Smith of The Nature Conservancy and Dr. Seth Riley of the National Park Service. Expert Workshop participants and other individuals and entities whose input or data contributed to these analyses are noted in the report.

The work was primarily supported by contracts and grants from the San Diego County Association of Governments and the California Department of Fish and Wildlife Local Assistance Grant Program. Funding for the experts workshop on connectivity across I-15 was provided by The Nature Conservancy, the National Park Service, and private donors.

The study's most important findings are:

1) GPS-collared mountain lions (during the current study period and previously) circulated in the southern, eastern, northern, and northwestern portions of the NCMSCP, and between the NCMSCP and adjacent NCCP lands. Resource selection function and movement function analyses by Dr.'s Zeller and Vickers found that mountain lions avoided areas of human development, as well as higher elevations and steeper slopes. Mountain lions preferred coastal oak woodland and riparian areas, and avoided agricultural areas, chaparral, coastal scrub, grassland, and barren areas. However, during movement, mountain lions tended to use higher elevations and coastal scrub more, along with oak woodlands and riparian areas, but still avoided human development, agricultural areas, chaparral, grassland, and open areas.

2) Resource selection function modeling was used to detect areas with a probability of use of 60% or greater, and habitat patch sizes that were at least 50km^2, the minimum home range size for a female in the study area. This resulted in a total of 2,577 km^2 being defined as suitable resource use (RU) habitat. For corridor modeling, resistant kernel (movement selection) models, and landscape genetic modeling were completed and compared. The landscape genetic corridors offered some additional areas of connectivity compared with the corridors based on the movement selection function. Because adequate conservation of mountain lions depends on both daily, fine-scaled movement, as well as movement over generations that results in the sharing of genetic material, resistance surfaces from both analyses were integrated together to produce a single resistant kernel corridor model. This model identified an additional 777 km^2 of key habitat for corridors that lay outside of the modeled RU patches. In addition, a Factorial Least Cost Path (FLCP) analysis was completed to compare to the corridor model, and better identify likely road crossing locations.

3) Resource selection and corridor modeling indicated that only 35% of RU patches and 47% of modeled corridors outside of RU patches in the NCMSCP and surrounding area exist on currently protected lands. Another 26% of RU patches and 12% of corridor lands outside RU patches are partially protected on Department of Defense (DOD), Native American Reservation, and Irrigation and Water District (I&WD) lands. Because mountain lion territory sizes (mean of 375 km^2 for males and 193 km^2 for females) are larger than most protected areas in San Diego County, mountain lions must routinely move across large unprotected areas and busy highways in order to survive, increasing their risk of mortality. Thus, as currently constructed, the protected area network and protected corridors in the NCMSCP and adjacent NCCPs do not appear to be adequate to promote long-term persistence of the current mountain lion population and its ecological functions without additional conservation action, including in the eastern part of San Diego County.

4) If secured for conservation, Pre-Approved Mitigation Area (PAMA) lands are expected to bolster the wildlife conservation network in the NCMSCP and surrounding NCCP areas in the future. Based on our resource selection and corridor modeling, if protection of 75% of currently designated PAMA lands is accomplished (the current conservation target), an additional 27% of modeled RU patches and 22% of corridors outside modeled RU patches will be protected, resulting in a total of 62% of modeled RU patches and 69% of corridors outside of RU patches being fully protected. However, even if partially protected (DOD, Native American Reservation, and I&WD) lands are added, 12% of RU patches, and 18% of

corridors outside of RU patches will remain as private lands and subject to development after all conservation actions are complete. Thus, our study findings should guide prioritization and possible re-examination of PAMA-designated lands, or other key lands acquisitions beyond current targets. Because of the importance of PAMA lands to the conservation network for mountain lions (and other wildlife), we feel it is critically important to proceed with protection of PAMA lands as rapidly as possible.

5) This genetic analysis by Dr.'s Ernest, Gustafson, and Vickers suggests that freeways and adjacent development appear to be exerting complete or nearly complete barrier effects on mountain lion physical and genetic connectivity in the region. Mountain lions throughout the region south of Interstate 10 (I-10) (San Diego, Orange, and southern Riverside County) appear to be genetically isolated from mountain lions in the rest of California north of I-10; and the mountain lion population west of Interstate 15 (I-15) remains at risk due to the combined negative effects of low population size, low genetic diversity, and low annual survival. This is of special concern given the well-documented extinction risks faced by similarly genetically restricted Florida panthers, and the genetically-similar mountain lions in the Santa Monica Mountains (Benson et al. 2016).

6) Though San Diego County mountain lions east of I-15 have higher genetic diversity than mountain lions west of I-15, the isolation from other California populations may have negative implications for long-term genetic diversity in the eastern population. It is uncertain whether connectivity remains between San Diego County mountain lions and those further to the east (Arizona) or south (Mexico) due to absence of available comparative samples from those areas, but what connectivity remains to the south may be further threatened by changes to border security measures or energy development.

7) Though this genetic analysis found that five previously undetected animals, and two previously known animals, appear to have crossed I-15 during the 2001-2016 period (either east to west or west to east), five are known deceased and the fate of the other two is unknown. Only one animal that has been indicated by genetics to have crossed I-15 is known to have reproduced (M86), potentially bolstering the population genetics of mountain lions west of I-15. However, M86, and nearly half of his known offspring, are also known to be deceased, suggesting that the high mortality rates in the regional mountain lion population reduce the potential for expansion of genetic diversity by potentially limiting the lifespans of genetically important animals that manage to cross existing barriers. Increased effort must be expended to increase genetic connectivity across both I-15 and the I-10 area to the north, and to reduce mountain lion mortality, in order to maintain or improve genetic diversity among this region's mountain lion populations.

8) Only two corridors that were identified by corridor modeling and Factorial Least Cost Path (FLCP) modeling crossed I-15 at existing safe crossing structures - the Temecula Creek Bridge in southern Riverside County, and the San Luis Rey River Bridge in San Diego County. The corridor crossing at the Temecula Creek Bridge was the only corridor that was continuous between large areas of habitat on both sides of I-15. Also, Experts Workshop participants scored the Temecula Creek Bridge site as the most viable I-15 crossing for mountain lions under current conditions, though improvements to the bridge and adjacent areas were advised.

9) Existing culverts south of the Temecula Creek Bridge are also within the crossing areas identified by the

corridor and FLCP modeling. Studies of existing culverts in that area (Stricker 2014) have confirmed some (minimal) use by wildlife such as bobcats; however, the steep vertical orientation of parts of these culverts and other design characteristics caused expert workshop participants to conclude that their potential for use by mountain lions is low. Experts Workshop participants ranked construction of a new crossing structure south of the existing Temecula Creek Bridge as the best way to augment current mountain lion and other wildlife connectivity across I-15.   Experts Workshop participants also emphasized that relying on one crossing structure to connect wildlife across two mountain ranges is unwise, thus they strongly advised construction of a new crossing structure (wildlife bridge or larger culvert) at a location south of the existing culverts.

10) Experts Workshop participants, as well as our research team, expressed concern that development proposals under consideration by the City of Temecula in the corridor area near the Temecula Creek Bridge will reduce the potential for mountain lion use of this already-constrained corridor, and further decrease the potential for critical mountain lion migration and gene flow into and out of the population west of I-15. Human presence in Pechanga and Temecula Creeks, and the Santa Margarita River, may be negatively affecting corridor function at this time, and human presence there may increase if additional recreational trail development and use accompanies housing construction in this area.

11) The other major corridor indicated by corridor and FLCP models that crossed I-15 at an existing major structure followed the course of the San Luis Rey River and crossed I-15 at that river bridge. However this corridor becomes less supported by the resistant kernel corridor model as the river flows west through major urban and agricultural development. Thus, the likelihood of this corridor allowing routine movement to or from the large core habitat areas to the west and north is lower than for the corridor that crosses I-15 at Temecula Creek. Nevertheless, this corridor should be closely examined for any conservation actions that could be taken to improve its function for mountain lions and other wildlife, and development or other activity that would further degradation its corridor function should be prevented.

12) Depredation permits issued after mountain lions killed domestic animals were the number one cause of death for GPS-collared mountain lions in San Diego County prior to 2013 (Vickers et al. 2015). During the period 2014–2016, sixteen additional mountain lions were confirmed killed in San Diego County as a result of depredation permits issued after they killed small livestock, suggesting that this remains a significant risk for area mountain lions. Depredation permit mortalities were almost all males, the key group that assures gene flow on the landscape, and almost all these mortalities were preventable with good livestock husbandry practices. All mortalities were mapped and were concentrated around the communities of Julian-Santa Ysabel and Descanso-Guatay, in a modeled RU and corridor area that is populated with scattered residences that often have small livestock such as goats. Increased research into predator deterrence methods and education of owners of small livestock in ways to reduce risk of predation of their livestock are both being employed by the UCD team and others to attempt to reduce this source of mortality in San Diego County mountain lions.

13) Other mountain lions died on highways in the County during the same 2014 – 2016 period. Busy San Diego County highways such as SR79, SR78, SR76, SR67, Valley Center Rd, and Wildcat Canyon / Barona Rd. were crossed 1,540 times by 51 GPS-collared mountain lions between 2001– 2016. During the same period,

25 un-collared and 6 GPS-collared mountain lions were killed on San Diego County highways, and highway deaths were the number two source of mortality for GPS-collared mountain lions in San Diego County (Vickers et al. 2015). We combined FLCP models with actual road crossing locations of GPS-collared mountain lions to identify roadway sections of highest concern. Because wildlife–vehicle collisions also pose a human safety risk, and because other wildlife such as deer often cross highways at the same locations as mountain lions, we believe that highway sections identified by the study deserve closer examination in order to identify potential improvements for reducing wildlife-vehicle collision risk, improve human safety, and improve connectivity.

14) Our genetic analysis of 146 individuals across the region allowed pedigree construction that detected first order (parent-offspring or sibling) relationships in 80% of the individuals, and also detected several instances of parent-offspring matings both east and west of I-15. The pedigree analysis, combined with GPS-collar data, confirmed that migration of males from their natal ranges to other habitat areas has occurred within the populations east and west of I-15; however, as noted elsewhere, migration has rarely successfully occurred across I-15, and no evidence of migration across I-10 emerged from this and other genetic analyses.

15) Our research team feels that these research findings and others that relate to mountain lion conservation and connectivity should be vigorously communicated to the public in order that public policy discussions relating to investments in conservation and infrastructure are based on the best science available and a common understanding of all pertinent research findings.

INTRODUCTION

The UC Davis Wildlife Health Center has been studying mountain lions in San Diego County and the surrounding region since 2001. Habitat fragmentation and barriers are exerting negative effects on the population, including low annual survival rates due to vehicle strikes, depredation permits, and other causes (Vickers et al. 2015), and movement and gene flow restriction across Interstate 15 and other barriers (Ernest et al. 2014; Vickers 2014, 2015).

San Diego County is conducting conservation planning for its North County Multiple Species Conservation Program (NCMSCP). Although the NCMSCP plan is not yet approved, the connectivity assessments (movement, habitat use, and genetics) conducted under this contract and simultaneous analyses (models development, workshop) conducted with separate funding, will help inform conservation and highway planning by key agencies and entities such as the U.S. Fish and Wildlife Service (USFWS), CDFW, counties of San Diego, Riverside, and Orange, other local jurisdictions, Caltrans, local transportation agencies, and conservation organizations. The findings presented here will allow better prioritization of conservation-related activities aimed at retaining and strengthening the habitat linkages (or wildlife corridors) between the NCMSCP and other San Diego County NCCPs as well as other NCCP areas within Riverside and Orange Counties.

In addition, the San Diego Management Strategic Plan (MSP) and Connectivity Strategic Plan which cover multiple San Diego NCCPs have identified the need to understand the connectivity of mountain lion populations within San Diego County, as well as connectivity to Riverside and Orange Counties. These plans recognize the need to conserve and connect protected lands and assure wildlife road crossings are constructed in the appropriate locations to ensure that the goals and objectives of the plans can be achieved at the required scale for the mountain lion and other wide ranging species.

The entire study area is within the original NCCP planning area addressed under the 1991 NCCP statute and planning documents. Regarding specific plan goals, the early approved NCCP plans in San Diego (e.g., MSCP Subregional Plan approved in 1998) and the Central-Coastal Orange County NCCP/HCP approved in 1996, strongly acknowledge the need to maintain connectivity beyond their borders. The MSCP in San Diego states: "Selected predator populations also should be monitored, and linkages should be maintained for movement of large predators." (Final MSCP Program Plan, page 6-11).

More specific direction is given in the Western Riverside MSHCP (page 5-26 and 5-79): "Reserve Managers will maintain or improve functionality of dispersal routes. The WRMSHCP identifies key crossings outside of their plan boundary that are relevant to their NCCP which includes "Interstate 15 that connect the Santa Ana Mountains with the Agua Tibia Wilderness-Palomar Mountains via Pechanga Creek or the possible "Rainbow" overpass". This is part of the LAG study and is also specifically referenced in the WRMSHCP (page 9-100) in Objective 2 (to include within the MSHCP Conservation Area Habitat Linkages and movement corridors between large habitat blocks that allow dispersal and movement of mountain lions and to areas outside of the Plan Area) and Objective 3 (".. to maintain or improve functionality of dispersal routes."

The research team's focus was to provide key information about puma movement and wildlife connectivity that is currently lacking at puma-specific scales in order to assist in prioritization of habitat for conservation of this species and others. The team also focused on informing highway planners about best locations for wildlife crossing improvements for highways in the area. This is an especially critical need along Interstate 15, which splits the NCMSCP, for enhancement of puma gene flow across that barrier. This study was also critical for planning of improvements along several other regional state highways due to the long timeframes involved with designing highway projects, and the need to define wildlife needs early in the planning process.

All of the research team's findings are reported here in order to better inform SANDAG, CDFW, and other entities involved with conservation of mountain lions and other wildlife in the region. This information is important for assuring that all of the above-mentioned approved NCCPs function as anticipated. Due to the wide-ranging nature of mountain lions and their large home ranges, the UC Davis team found that individual mountain lions often utilize multiple conserved cores and corridors that include areas outside the primary study area for this project. Thus, mountain lions captured in the study area have helped to inform connectivity in the larger region. For the purposes of overall conservation planning and corridor definition, areas of southwestern Riverside and southern Orange Counties are included in the team's overall assessment.

PROJECT PERSONNEL:

Dr. Winston Vickers is a wildlife veterinarian and is the field lead and co-PI with Dr. Walter Boyce of the ongoing Southern California Mountain Lion Project of the UC Davis Karen C. Drayer Wildlife Health Center. Dr. Vickers has extensive knowledge of the area, the data that has been generated by GPS-collared mountain lions during the course of the project, and regional landscape conservation and road planning and wildlife crossing issues. He is an author or co-author of numerous reports and peer reviewed publications relating to mountain lions in the southern California region.

Dr. Holly Ernest is a professor, ecological geneticist and wildlife research veterinarian. She has researched mountain lion ecology and genetics in California for nearly 20 years. Dr. Ernest and her team have several publications involving genetics, diseases, and health of mountain lions and other wildlife species ranging from bighorn sheep and black bears to hummingbirds and raptors (http://www.vetmed.ucdavis.edu/vgl/wildlife/publications.html). Most recent mountain lion publications are published in the journals PLOS ONE (Oct 2014 – coauthored with Dr.'s Vickers and Boyce) and Current Biology. She has joint appointments at UC Davis (Professor emeritus of wildlife genetics and population health) and University of Wyoming (Wyoming Excellence Chair and Professor of Disease Ecology: Ecology and genomics of wildlife and their pathogens). Dr. Ernest's lab generated the genetic data, and provided statistical analysis.

Dr. Kyle Gustafson, postdoctoral researcher in Dr. Ernest's University of Wyoming lab, conducted genetic data analysis including molecular pedigree reconstruction, and contributed to writing of this report. He is a broadly-trained population ecologist and, over the last 4 years, has published 10 peer-reviewed papers on the population biology of invertebrate and vertebrate organisms. He is currently working on several landscape-level population genetics projects in Holly Ernest's laboratory, including for mountain lions and black bears.

Dr. Kathy Zeller of the University of Massachusetts has been designing and implementing corridors for jaguars and mountain lions for over a dozen years and has published 12 papers in peer-reviewed journals about her work. She has worked with Drs. Vickers, Boyce, and Ernest on modeling resource use, movement, and connectivity for mountain lions in the area encompassed by the Southern California Mountain Lion Project.

Dr. Walter Boyce is a faculty member at the U. C. Davis School of Veterinary Medicine and former Director of the Wildlife Health Center. He has researched various aspects of mountain lion ecology, disease, and movement patterns since 2001 and has published numerous reports and peer reviewed publications relating to mountain lions and other wildlife species. He established and initially directed the Center's Southern California Cougar Project, and later served as Co-PI with Dr. Vickers. He provided overall advising and valuable input throughout the project. He assisted with reviewing the project report during preparation

Participants in the three-day Experts Workshop that was conducted in January, 2015 under the direction of Trish Smith of The Nature Conservancy, Dr. Vickers, and Dr. Seth Riley of the National Park Service in order to specifically discuss, evaluate, and rank locations and designs for infrastructure to improve connectivity (undercrossing, overcrossings, fencing, etc.) for the I-15 and 101 Freeways were:

- Dr. Paul Beier, with Northern Arizona University, is a professor of wildlife biology who is widely recognized as one of the nation's leading experts on habitat connectivity and the design of wildlife corridors. He has studied the movements of mountain lions in southern California, has published numerous journal articles on designing, conserving, and managing functional corridors in urbanizing areas, and is the founder of CorridorDesign.org.
- Dr. Anthony Clevenger is a senior research scientist at the Western Transportation Institute, Montana State University who has been studying road effects on wildlife populations in Banff and the surrounding national and provincial parks in the Canadian Rocky Mountains since 1996. During his 20+ years of research, Dr. Clevenger's interests have been broad and ecologically based, but have been weighted towards the ecological effects of roads and the conservation of small remnant populations of carnivores.
- Dr. Patricia Cramer is a Research Assistant Professor at Utah State University. Her research focuses on transportation ecology, wildlife connectivity, and carnivore and ungulate movement. She is nationally renowned advocate for wildlife crossings, and has conducted extensive evaluation of wildlife crossing structures throughout North America and developed recommendations for their construction.
- Julia Kintsch is an ecologist specializing in conservation planning, road ecology, large landscape conservation, and collaborative problem-solving. She is recognized across North America as an expert in wildlife crossing siting and design, offering a unique understanding of the features that influence successful passage for species ranging from salamanders to deer to the elusive Canada lynx. Following an active career working for non-profit organizations such as Tthe Nature Conservancy, Southern Rockies Ecosystem Project, and Freedom to Roam, she launched ECO-resolutions LLC in 2008.
- Dr. Patrick Huber is a Project Scientist with the Information Center for the Environment at the University of California, Davis. He earned a Ph.D. in geography at UC Davis and wrote his dissertation on spatial scale and conservation planning. His work focuses on conservation planning, landscape connectivity, and reserve design primarily in California.
- Dr. Kathy Zeller (Biography above)
- Numerous other knowledgeable local researchers and wildlife agency personnel also attended the final day of the workshop and provided input.

Field activities were conducted, and were dependent for success, on the assistance of U.C. Davis staff members P.J. Falatek and Jamie Bourdon, Barry Martin of the Wildlife Tracking Company, Carole Bell of The Nature Conservancy, and Pablo Bryant of San Diego State University, Jeremy Zagarella and members of the Pauma Tribe of Luiseno Indians, Kurt Broz and members of the Pala Band of Mission Indians, as well as volunteers from the Institute for Wildlife Studies, CDFW, and other organizations and individuals. We are extremely appreciative of their assistance.

Properties where camera and capture activities occurred during this project included those owned or managed by the San Diego City Parks Department, San Diego and Riverside County Parks Departments, CDFW, the Pauma Tribe of Luiseno Indians, the Pala Band of Mission Indians, the City of Escondido, CalTrans, Vista Irrigation District, the Rainbow Municipal Water District, San Diego State University, the Western Riverside County Regional Conservation Authority, and several private properties. The project could not have been

completed without the wonderful access and cooperation we received from these entities and their personnel; we are grateful.
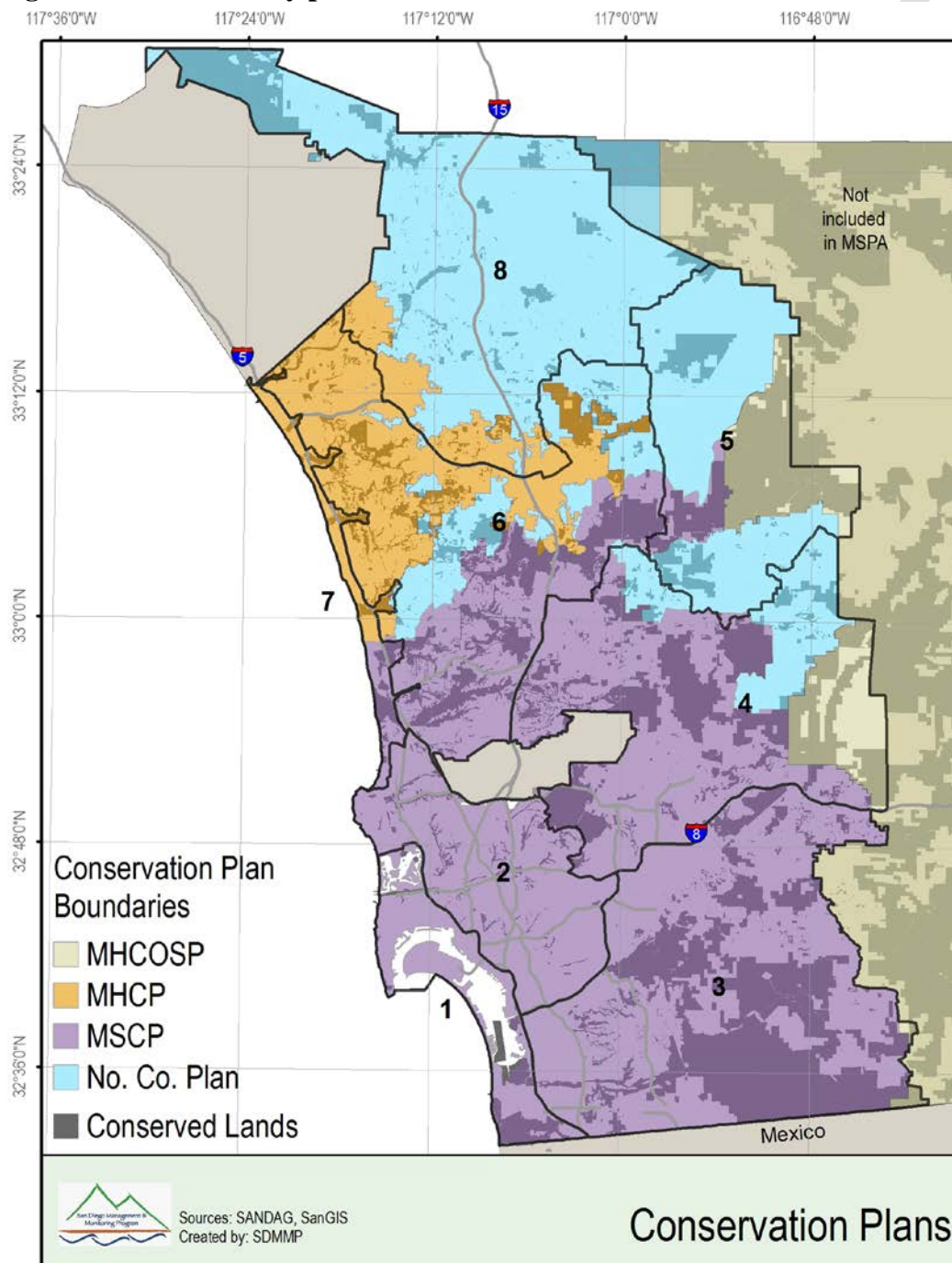
STUDY AREA

The NCMSCP (No. Co. Plan) area involves portions of San Diego County in Management Strategic Plan Area Management Units (MU's) 4, 5, 6, and 8, and links to NCCP areas within southwestern Riverside County, and NCCP preserves in Orange County. Interstate 15 (I-15) bisects MSP MU's 6 and 8 north to south, as well as similarly dividing the NCMSCP and San Diego County's Multi-Species Conservation Plan (MSCP) and Multi-Species Habitat Conservation Plan (MHCP) areas to the south (Figure 1).

Figure 1 – North county plan area with other core conserved habitat areas

The UC Davis Southern California Mountain Lion Project has been studying mountain lions in various portions of these named conservation areas since 2001. The overall UCD project study area ranges from Riverside and San Bernardino Counties in the north to the U.S.-Mexico border in the south (Figure 2). Interstate 10 and the Salton Sea approximately define the northern and eastern boundary, with the Pacific Ocean defining the western boundary.

Because this current project is focused on connectivity within the NCMSCP, and also between it and adjoining NCCPs, the study area for our purposes was designed to highlight the overall importance of the northern San Diego Country area in a greater landscape context (Figure 2).

Figure2. Overall Southern California Mountain Lion Project Study Area and the Current Study Area and NCMSCP
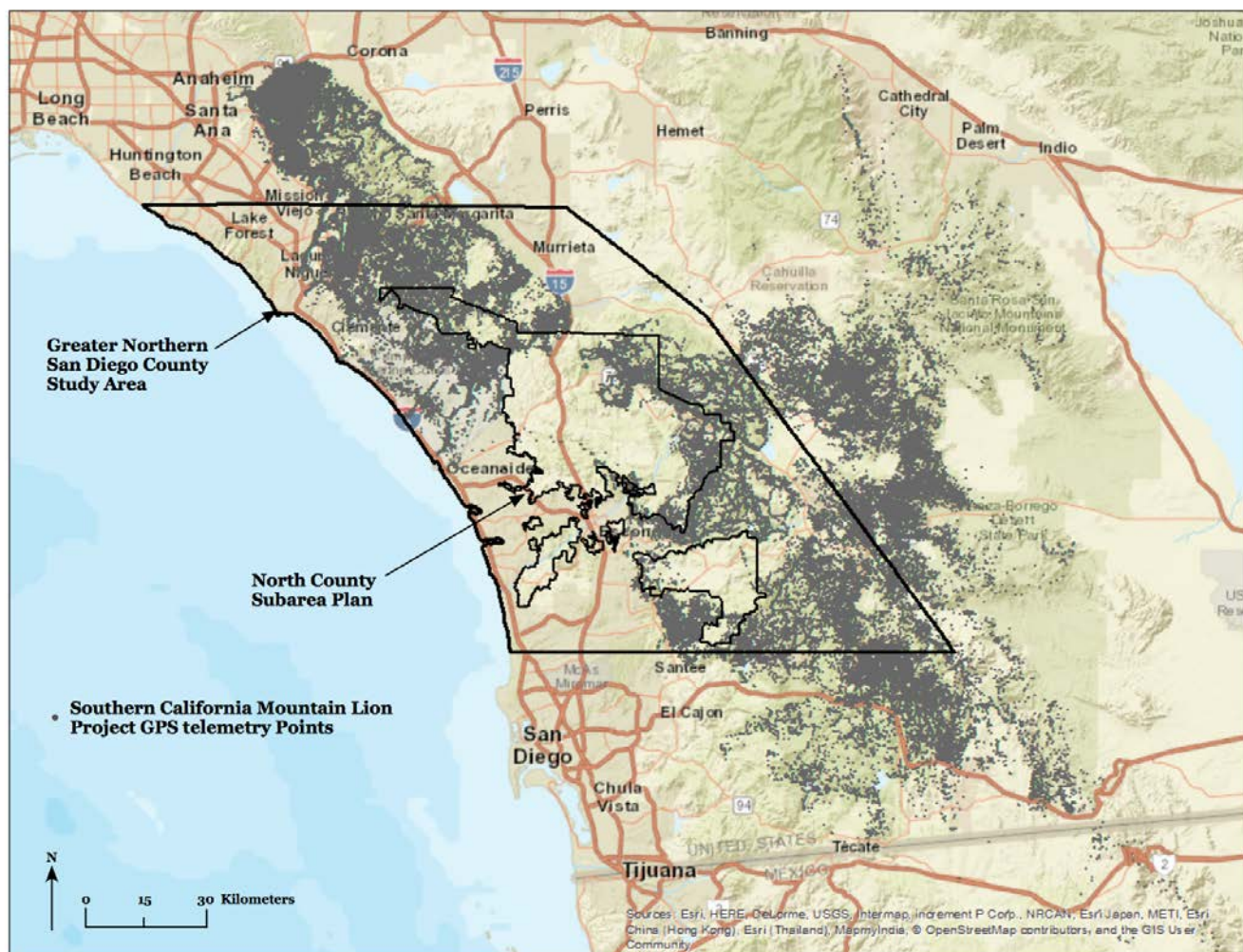
Task List (in order of appearance in the Methods section – reporting of some Tasks are combined in the Results section):

SANDAG Task 1 - Determine the locations within the study area where mountain lion movement is occurring for baiting and potential trapping, and documentation of habitat use.

SANDAG Task 2 – Capture and GPS collar mountain lions in the NCMSCP.

SANDAG Task 3 - Download data from GPS collars and record mortalities in the study area.

SANDAG Task 4 – Isolate and characterize DNA from captured mountain lions and others in the study area. Perform genetic analysis and pedigree and family relationship reconstruction. Transmit genetic data to Dr. Kathy Zeller (See CDFW-LAG Task 5 below) for landscape genetics analysis.

CDFW-LAG Task 1 - Perform a resource selection function analysis and identify critical resource use patches for mountain lion across the study area.

CDFW-LAG Task 2 -Perform a movement selection function analysis to estimate probabilities of movement across the study area.

CDFW-LAG Task 3 - Identify mountain lion connectivity across the study area by modeling two types of corridors, Factorial Least-Cost Paths and Resistant Kernels. Use Factorial Least-Cost Paths combined with mountain lion GPS paths to identify most likely road crossing locations. Examine landscape level connectivity with resistant kernels.

CDFW-LAG Task 4 - Use genetic data in a landscape genetics analysis to estimate mountain lion resistance to movement. The correlation between this resistance surface and that of the GPS-derived surface will help to identify and flesh out any potential gaps in the connectivity analysis.

CDFW-LAG Task 5 – Using resource use patches, corridors, and road crossing locations will identify a conservation network for mountain lions in the study area and provide a prioritization framework for conservation and road crossing improvements

EXPERTS WORKSHOP – Convene a workshop of connectivity experts from around North America, along with local resource agency and other knowledgeable personnel, to define the best locations along I-15 for wildlife crossing structure improvement or new construction.

SANDAG Task 5 – Generate a report to include databases of all GPS points, camera findings, and details of mountain lions captured or mortalities recovered, results of all analyses (including from CDFW-LAG funded habitat, movement, and corridor modeling) and the I-15 experts workshop, and define lands and corridors currently most likely to be utilized by mountain lions.

METHODS:

METHODS - SANDAG Task 1 - Determine the locations within the study area where mountain lion movement is occurring for baiting and potential trapping, and documentation of habitat use.

An array of automatically triggered trail cameras were placed across the study area in locations determined by track or other sign of likely mountain use. These were utilized primarily to determine the locations within the study area where mountain lion movement was occurring for baiting and potential trapping, and documentation of habitat use. Cameras were placed and monitored throughout the NCMSCP and the movement corridor area immediately to the north in Riverside County. Cameras had previously been placed in some portions of the NCMSCP in the research team's previous assessment of the San Diego County MSCP in 2013-2014 and these results are also reported here.

METHODS - SANDAG Task 2 – Capture and GPS collar mountain lions in the NCMSCP.

Mountain lions were captured under CDFW Scientific Collecting Permit number 9875 and U.C. Davis Institutional Care and Use Committee authorization number 17233. Capture techniques involved cage captures utilizing roadkilled deer as bait items (Illustration 1). Capture methods were identical to those detailed in Vickers et al. (2015) (Illustrations 2, 3). Captured mountain lions over 50 pounds body weight were fitted with GPS collars and released at the site of capture.

Illustration 1. Mountain lion investigating road-killed deer placed as bait in area where trial cameras had indicated regular mountain lion visitation

Illustration 2. Dr. Winston Vickers sedating mountain lion in trap with Dan Sforza (CDFW) assistance

Illustration 3. Mountain lion after placement of GPS collar and release at the capture site

METHODS - SANDAG Task 3 - Download data from GPS collars and record mortalities in the study area.

GPS data points transmitted successfully from the GPS collars via satellite were downloaded regularly (Figure 2). Full datasets were collected from collars when recovered after their timed dropoff mechanisms caused them to be released from the animals. If collars were not recovered due to electronic or mechanical malfunctions, partial datasets that had been retrieved via UHF or satellite downloads were utilized in analyses.

Minimum convex polygons (100% MCPs) were calculated for GPS-collared mountain lions in the current study as well as selected animals collared for the broader UCD regional study. Minimum convex polygons denote the general size of areas of use of individual animals, and are not intended to denote core home ranges. MCPs are often quite variable and can overestimate the area utilized by animals that are dispersing, shifting home ranges, or ranging in desert areas are expected to have polygons that are larger than average.

All mountain lion GPS datapoints collected to date have been made available to SANDAG and CDFW, as well as San Diego County Planners and other governmental or conservation entities in the region to be utilized for planning and actions that may enhance mountain lion and other wildlife persistence in the region.

All mountain lion mortalities that were detected (GPS-collared or uncollared) were documented as to location (Illustrations 4 and 5), sampled for DNA, and bodies transported to diagnostic labs for necropsy if in adequate condition (Illustration 6).

Illustration 4. Location on SR 67 where mountain lion M107 was struck and killed. Biologist Dale Ritenour points to location where M107 body was found.

Illustration 5. M107 at roadside after recovery

Illustration 6. Group of deceased mountain lions from San Diego County in 2015 transported to diagnostic lab. All mountain lions pictured here were killed on depredation permits except one individual that was killed by a vehicle.

METHODS - SANDAG Task 4 - DNA isolation and genotyping with genetic analysis and pedigree and family relationship reconstruction. Transmission of genetic data to Dr. Kathy Zeller (See CDFW-LAG funded Task List below) for landscape genetics analysis.

Blood or tissue samples were collected from all captured and deceased cougars that the research team encountered in the study area or adjacent regions during the study period, and DNA was extracted and characterized across 44 microsatellites by Dr. Holly Ernest's lab at the University of Wyoming. DNA samples collected and similarly characterized previously by Dr. Ernest's lab were also included in the analysis, for a total of 146 individual mountain lions (Figure 3). Dr. Kyle Gustafson and Dr. Ernest then analyzed the genetic data and created pedigrees for all the animals for which genetic connections could be ascertained. Comparisons between regional populations and populations elsewhere in California were also performed.

Measures of population genetic diversity such as number of alleles, heterozygosity, Shannon index, inbreeding coefficients, and internal relatedness, were derived utilizing the methods and software described in Ernest et al. (2014). For population assignment, programs GENELAND (Guillot et al. 2005b) and TESS (Durand et al. 2009) were used to assign the 146 mountain lions (genotyped at 44 microsatellite loci) to populations. Population assignment analyses followed software developer recommendations. .

For pedigrees, programs CERVUS (Slate et al. 2000) and COLONY (Jones and Wang 2010) were used to construct family relationships where possible for all 146 mountain lions. Pedigree analyses followed developer recommendations. Draft population assignments and draft pedigrees were checked against known lifespan periods and known areas of circulation based on aging and GPS data to ascertain likelihood of indicated pair matings and offspring production.

Figure 3. Locations where live and deceased mountain lions were sampled for genetic analyses.
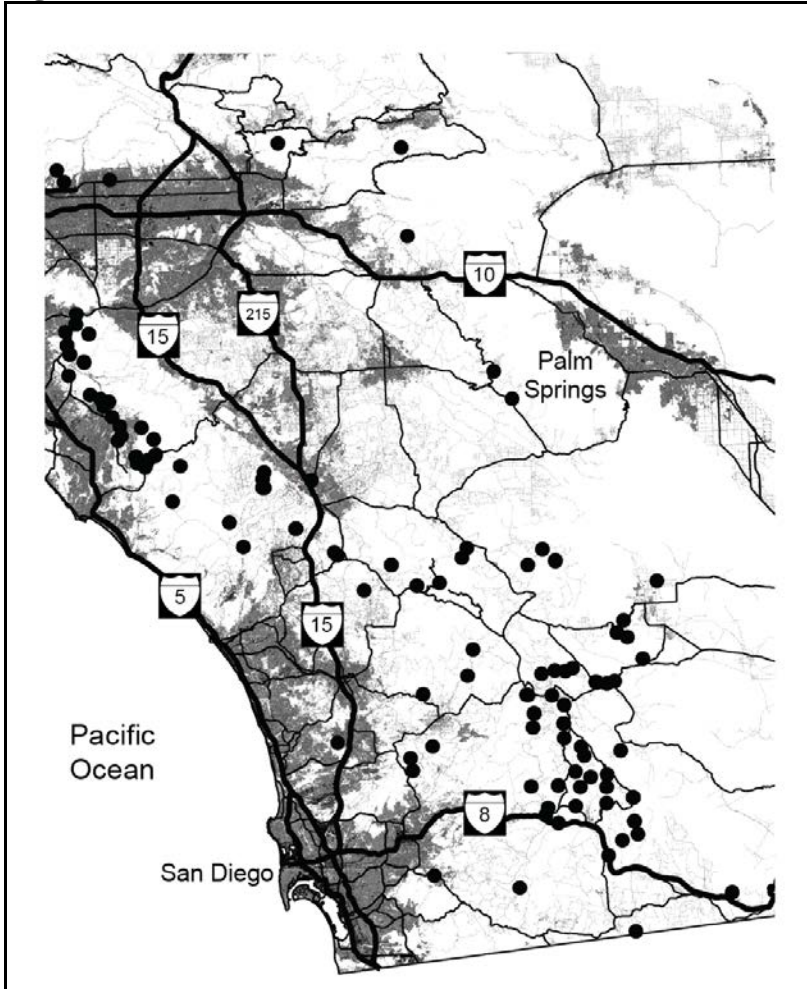
These DNA sequences and analyses were compared to results from other regions of California, especially adjacent areas immediately to the north in Riverside and San Bernardino Counties. The DNA data were also used by our collaborator Dr. Kathy Zeller in validating movement models and creating landscape genetics analyses under separate funding by a CDFW-LAG grant.

Note relating to the current genetic analysis results being reported here:
All analyses are based on microsatellite data and use of a variety of different software programs. Results could change (usually minor but possibly more significant) when subjected to peer review or when compared with pending/different analyses being conducted under other funding sources with other collaborators. Precision of molecular pedigree reconstruction (making family trees using DNA data) depends on a number of factors including amount of DNA data available and percentage of all possible parents present in the sample set. With mountain lions, the percentage of all possible parents that are represented in the sample set is unknown, but likely higher in the Santa Ana Mountains than the Eastern Peninsular Range (more open habitat, larger area than Santa Ana habitat). Other new and in-progress genetic research in the Ernest Lab being conducted on mountain lions in this area include the use of high density single nucleotide polymorphism (SNP) data sets. SNPs may provide more detailed data for understanding mountain lion connectedness, relatedness, and familial

relationships. Also, when additional mountain lion samples (especially additional potential parents) are analyzed in the future, changes in the pedigree may result.

METHODS - CDFW-LAG – All resource selection and movement modeling

Dr. Zeller, in collaboration with Dr. Vickers, utilized the research team's extensive mountain lion data set to develop resource selection and movement selection functions, and to identify movement corridors and road crossings.   To reflect current mountain lion habitat use and movement, we restricted this data set to mountain lions that were collared from 2005 to present.

Home ranges were calculated using data from mountain lions with at least five months of data. Collar duration for the cats ranged from 5 to 32 months, and collar acquisition interval ranged from 5 minutes to 6 hours. Data were examined to determine if individuals had moved from their natal home range to a new home range area. If dispersal movement was identified, we excluded these individuals from the analysis. This resulted in a total of 31 mountain lions (Males= 12, Females = 19). We subset the mountain lion data to every six hours so that the data were consistent and to reduce any autocorrelation that may have been present with the more frequent fixes. This resulted in 25,157 points for the analysis (Figure 4). Kernel density home ranges were derived using the reference bandwidth and an unconstrained bandwidth matrix (Bauder et al. 2015). We used 90% of the entire utilization distribution as the final home ranges for each individual.

Figure 4. Mountain Lion GPS telemetry points from 2005 to present from mountain lions with at least 5 months of data.
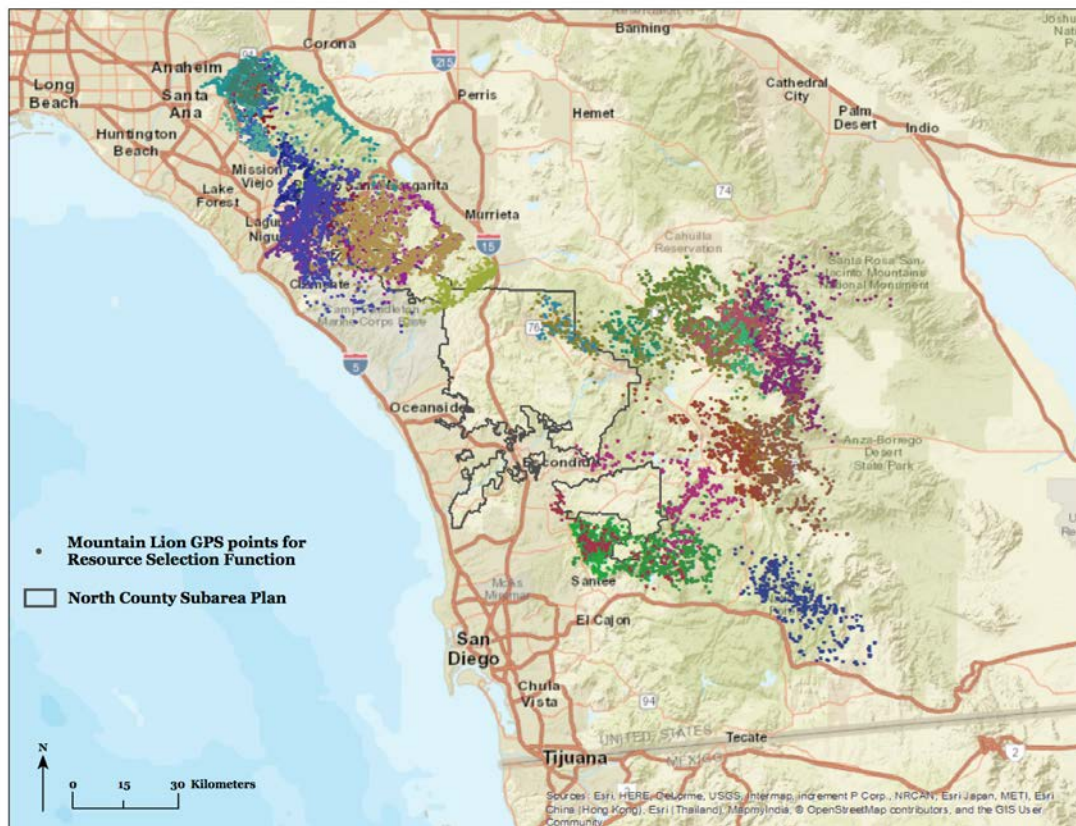
For the resource use and movement selection functions, we used predictor variables that have been shown to influence mountain lion habitat use and movement. These included: elevation (Alexander et al. 2006; Allen et al. 2014; Burdett et al. 2010; Wilmers et al. 2014), percent slope (Dickson and Beier 2006; Dickson et al. 2005; Wilmers et al. 2014), terrain ruggedness (Burdett et al. 2010), land cover types aggregated for the study area (Burdett et al. 2010; Wilmers et al. 2014), roads (Dickson et al. 2005; Wilmers et al. 2014; Gray et al. 2016), and urban areas (Dickson et al. 2005; Wilmers et al. 2014; Gray et al. 2016). Roads were represented in three ways: either classified as Primary, Secondary and Tertiary roads and given weights of 5, 2.5, and 1 respectively; classified as Primary and Secondary roads (leaving out all other roads classes) and given weights of 2.5 and 1 respectively; or as Primary roads only. Urban areas were represented as High, Medium, or Low Density and given weights of 5, 2.5, and 1 respectively. Variables, their sources and year are provided in Table 1. All variables were represented with a 30m spatial resolution.

Table 1. Predictor variables used in the Resource Use and Movement Selection Functions.

	Variable	Source/Derivation	Year	Citation
Topographic	Elevation	National Elevation Dataset	2009	USGS 2009
	Percent Slope	Derived from National Elevation Dataset	-	-
	Terrain Ruggedness	Total curvature derived from National Elevation Dataset with DEM Surface Tools (Jenness 2013)	-	-
Land cover Type	Agriculture	Aggregated agricultural classes from CalVeg	2014	CalVeg
	Chaparral	Aggregated chaparral classes from CalVeg	2014	CalVeg
	Coastal Scrub	Aggregated scrub-type classes from CalVeg	2014	CalVeg
	Coastal Oak Woodland	Aggregated woodland classes from CalVeg	2014	CalVeg
	Grassland	Aggregated grassland classes from CalVeg	2014	CalVeg
	Barren/Open Water	Aggregated barren and open water classes from CalVeg	2014	CalVeg
	Desert	Aggregated desert classes from CalVeg	2014	CalVeg
	Riparian	Aggregated riparian classes from CalVeg	2014	CalVeg
Human Development	Urban; Classified as High, Medium, and Low density Urban Areas	National Land Cover Data	2011	National Land Cover Data
	Roads; Classified as Primary, Secondary, and Tertiary	TIGER	2014	U.S. Census Bureau
	Roads; Classified as Primary, and Secondary	TIGER	2014	U.S. Census Bureau
	Roads; Classified as Primary	TIGER	2014	U.S. Census Bureau

METHODS - CDFW-LAG Task 1 - Perform a resource selection function analysis and identify critical resource use patches for mountain lion across the study area

We created a hierarchically integrated resource selection surface (HI-RSF) by performing both a home range selection function (HRSF) and a point selection function (PSF) and combining the two resultant predictive surfaces (DeCesare et al. 2012). This predictive surface represents both home range selection and resource use within home ranges (Level II and III selection according to Johnson 1980). Both the HRSF and the PSF are analyzed in the 'used' and 'available' framework typical of resource selection functions (Manly et al. 2002). With this design, preferred habitats are used in greater proportions than their availability and avoided habitats are used in lesser proportions than their availability. All data analyses were performed in the R software environment (R Core Team 2016).

For the HRSF, we distributed 'used' points within the already identified home ranges and distributed 'available' points in a buffer around the home ranges. The buffer size was based on the maximum observed movement distances across the home ranges. Because it has been shown that mountain lions select for landscape features at different spatial scales, we calculated our used and available data within 10 ecological neighborhoods of varying sizes (50 m, 100 m, 200 m, 500 m, 1000 m, 2000 m, 4000 m, 6000 m, 8000 m, 10000 m; Zeller et al. 2014; Zeller et al. 2016). We developed multi-scale HRSFs using a two-stage approach (McGarigal et al. 2016). In the first stage, we ran univariate logistic regression models to identify the characteristic scale of selection for each landscape variable as indicated by the lowest Akaike Information Criterion Value corrected for small sample size (AICc; Burnham & Anderson 2002). In the second stage, we combined the optimal scales for each landscape variable into a multiple logistic regression model (omitting the lesser performing variable of any pair that had a correlation greater than 0.6). Because we thought all the variables would have some influence on puma habitat use, we fit all possible subsets of our predictor variables and ranked the models using AICc. We obtained our final model by averaging any models within 2 AICc units of the best model.

For the PSF, we used the 6-hour mountain lion telemetry points as our 'used' data. We paired each used with a surrounding 'available' area weighted by the Pareto distribution. This distribution best represented the movement of mountain lions in the study area. To examine different scales of selection, we used the following radii for the Pareto kernel: 241m, 408m, 681m, 915m, 1123m, 1317m, 1602m, 1850m, 2049m, 2298m, 2312m, 2797m, 3044m, 3104m, 3479m, 3819m, 3994m, 4099m, and 4461m. We used the same two-step modeling approach as described for the HRSFs, but we used a paired or conditional logistic regression model (Compton et al 2002).

We predicted the relative probability of habitat use across the study area from our final HRSF and final PSF models. We multiplied these two predictive surfaces together and rescaled the final surface from 0 – 1. This resulted in a hierarchically integrated predictive surface with probabilities of use ranging from 0-100%. We then smoothed this surface and used a probability of use of 60% as the cutoff to identify resource use patches. For each resource use threshold, we then retained patches that were at least $51km^2$, the minimum home range size for a female in the study area (see home range results below).

METHODS - CDFW-LAG Task 2 - Perform a movement selection function analysis to estimate probabilities of movement across the study area.

We performed Movement Selection Functions (MSFs) to estimate the relative probability of movement for mountain lions across the study area. We took much the same approach as for the PSFs above, but instead of individual GPS points our units of inference were the daily paths used by mountain lions. Our previous work has shown that biases are introduced into MSF results at 1-hour (Zeller et al. 2016) and thus restricted our use of data to mountain lions from 2005 to present with either a 5-min or 15-min fix interval. These individuals also had to have at least 2 weeks of data at this high fix interval (Figure 5). This resulted in a total of 39 mountain lions (Males= 20, Females=19) and 1,076 paths for the MSF analysis (Figure 5)

Figure 5. Mountain Lion GPS telemetry points from 2005 to present at a 5-min or 15-min GPS collar fix interval.
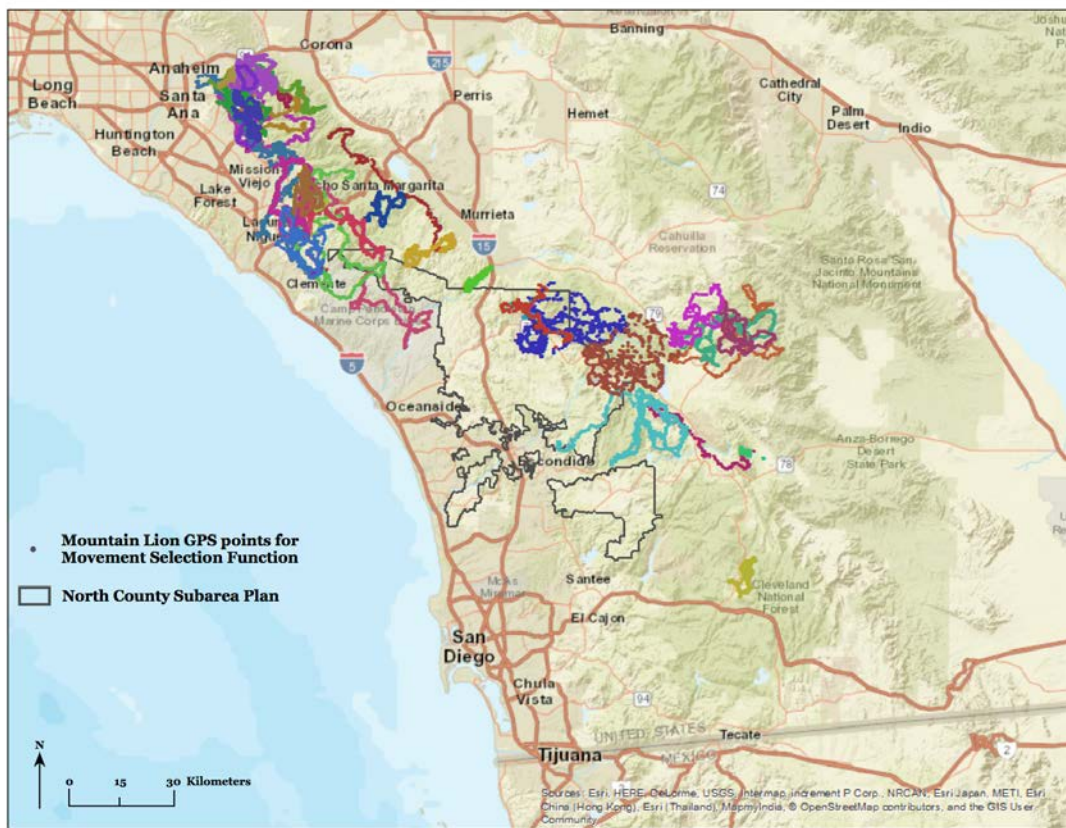
We estimated the used data as the proportion (for categorical data) or mean (for continuous data) of each predictor variable within a 30m uniform buffer around each daily path. The available data were the proportion or mean of the predictor variables around each path weighted by the 19 Pareto kernels described above. We ran paired logistic regression models and used a two-stage approach for the multi-scale MSF models via the same process described for the RSF analysis above. After obtaining a final fitted model, we predicted the relative probability of movement across the study area. We took the inverse of this probability of movement surface to estimate resistance (low probability of movement areas resulted in a higher resistance and vice versa).

METHODS - CDFW-LAG Task 4 - Use genetic data in a landscape genetics analysis to estimate mountain lion resistance to movement and complement the resistance surface derived from the Movement Selection Functions.

The same genetic data as described above in the 'DNA Analysis' section was used except for 7 individuals that were sampled outside of the main study area. Therefore, out of the 146 individuals described above, we used 139 for this analysis (Figure 6).

Figure 6. Locations of samples from 139 individual mountain lions used in the landscape genetics analysis.
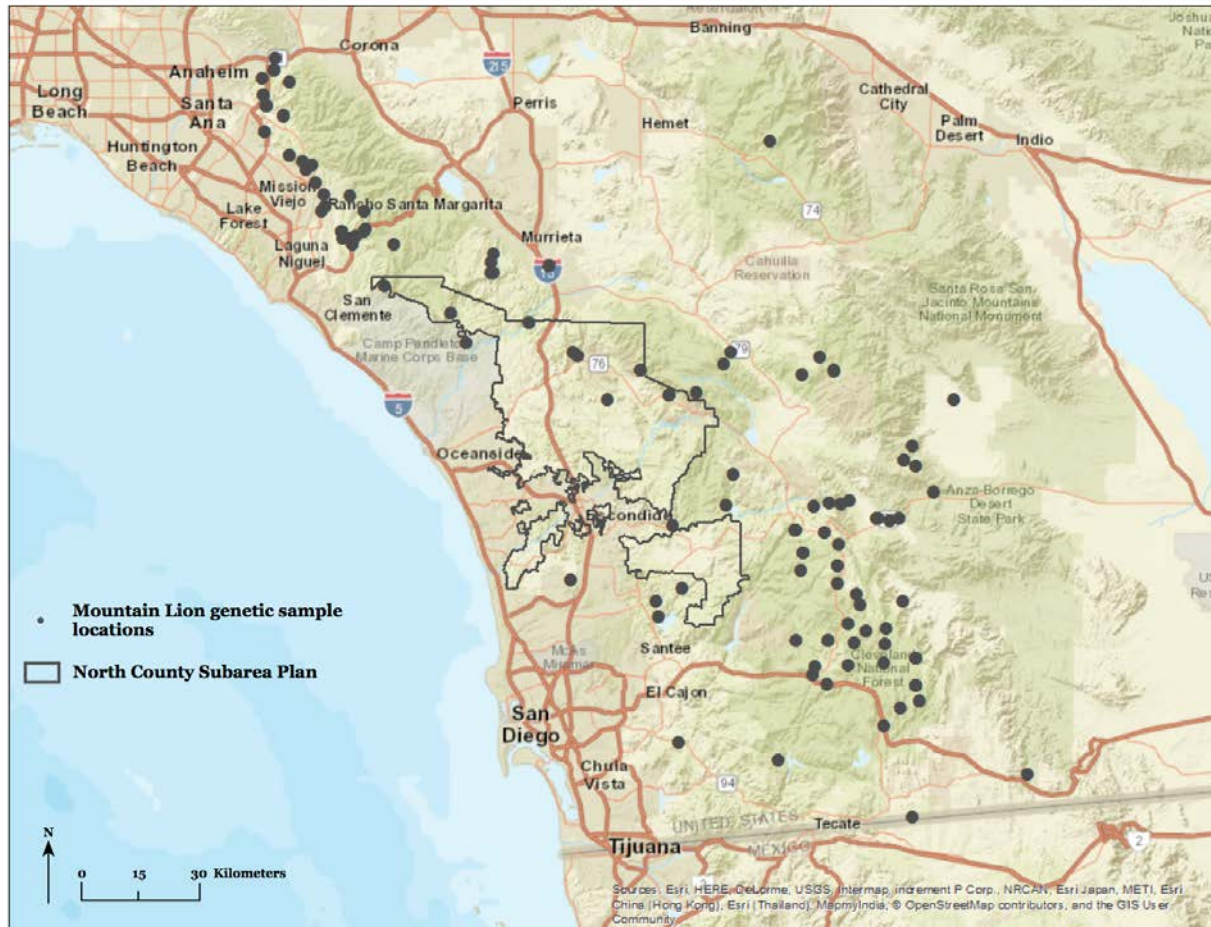
Landscape genetic approaches aim to correlate observed genetic distances among individuals or populations with geographic distances. These geographic distances are calculated as the least-cost distance or resistance distance among individuals. This process requires *a priori* defining a resistance surface across which geographic distances can be calculated. We explored several different representations of resistance for each one of our predictor variables. Specifically, we represented each variable at four spatial scales by smoothing each surface using a Gaussian kernel with the following bandwidths: 100m, 500m, 2000m, and 6000m. We then applied each of seven functions to transform the smoothed variable into a resistance value of 1-100. Positive transformation functions were used to represent increasing resistance as the values of that variable increased. We used the following positive transformations: linear, monomolecular concave, and monomolecular convex.

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Negative transformation functions were used to represent decreasing resistance with decreasing values of that variable. We used the following negative transformations: linear, monomolecular concave, and monomolecular convex. We also used the inverse Ricker transformation to account for variables that might have a low resistance at moderate values. Therefore, for each variable we tested a suite of 28 *a priori* resistance surfaces.

We calculated pairwise genetic distances among all 139 individuals using Nei's distance. We calculated pairwise geographic distance distances by calculating the least cost path distance between all individuals across each *a priori* resistance surface. We then compared all the *a priori* resistance surfaces for a variable by running linear mixed effects models that accounted for the pairwise structure of the distance matrices following the maximum likelihood population-effects (MLPE) method (Clarke et al. 2002; Van Strien et al. 2012).

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

We derived our final landscape genetic resistance surface by summing the resistance surfaces for the variables in the final model and rescaling from 1-100.

METHODS - CDFW-LAG Task 3 - Identify mountain lion connectivity across the study area by modeling two types of corridors, Factorial Least-Cost Paths and Resistant Kernels. Factorial Least-Cost Paths combined with mountain lion GPS paths locations will identify potential road crossing locations. Examine landscape level connectivity with resistant kernels.

To derive our final resistance surface, we multiplied the resistance surface we obtained from the MSF with that from the landscape genetics analysis and rescaled the resistance values from 1 – 100. This results in a resistance surface akin to the hierarchically integrated resource selection function surface described above and accounts for both coarse scale movement that results in successful dispersal and breeding and fine scale movements that reflect moment-to-moment movement decisions.

We modeled connectivity across our integrated resistance surface using two different approaches, factorial least-cost paths (FLCP; Cushman et al. 2009) and resistant kernels (Compton et al. 2007). All connectivity models were run in the UNICOR software package (Landguth et al. 2011). FLCPs are the product of identifying the least-cost path between all pairs of source/destination points. Resistant kernels simulate dispersers moving away from each source point according to a threshold dispersal distance and a resistance surface. FLCPs have been shown to better model road crossing locations while resistant kernels have been shown to offer a more synoptic view of connectivity across the landscape (Cushman et al. 2014).

We ran both models using source/destination points sampled from the resource use patches identified in Task 1. For FLCP analysis we identified 500 source/destination points by probabilistically sampling on the RSF surface within the resource use patches identified in Task 1. For the resistant kernels we identified 2,000 points by probabilistically sampling from within the resource use patches on the RSF surface. We were also able to

account for a dispersal threshold in the resistant kernel model. We set the dispersal threshold at 100km which reflects an average dispersal distance for mountain lions in this landscape (Vickers et al. 2015). We selected fewer points for the FLCP analysis due to computational limitations. By locating points in resource use patches and selecting points in higher probability of use pixels, we hoped to identify realistic source/destination points.

The FLCPs were combined to get a count, at every pixel in the study area, for how many least-cost paths crossed that pixel. We identified all pixels across the study area that had at least 100 least-cost paths passing through. Points where these pixels intersected with primary and secondary roads of concern throughout the study area were identified as probable road crossing locations. We identified movement corridors by taking the top 25% of the resistant kernel surface.

METHODS - CDFW-LAG Task 5 – Using resource use patches, corridors, and road crossing locations identify a conservation network for mountain lions in the study area and provide a prioritization framework for conservation and road crossing improvements.

Results from Tasks 1–4 were combined to create a mountain lion conservation network across the greater northern San Diego County study area. This conservation network was then combined with already-protected areas and proposed protected areas to identify potential gaps in protection and directions for future conservation efforts.

METHODS - EXPERTS WORKSHOP – Convene a workshop of connectivity experts from around North America, along with local resource agency and other knowledgeable personnel, to define the best locations along I-15 for wildlife crossing structure improvement or new construction.

A three-day workshop of invited connectivity experts from around North America was held in collaboration with The Nature Conservancy and The National Park Service to examine potential areas along I-15 and U.S. 101 where enhancement of existing wildlife crossing structures or construction of new structures would potentially be most beneficial to wildlife connectivity. Site visits and discussions with the invited experts occurred on the first two days, on the third day the experts met with local resource agency, highway, and other knowledgeable local personnel in a round table workshop format. In relation to I-15, the area of evaluation was based largely on detailed linkage assessments completed by South Coast Wildlands (2004, 2008), and further informed by wildlife movement studies and modelling efforts (Gibbons 2008, Tracey and Crooks 2011, Zeller et al 2015, Zeller et al. in prep., Huber unpublished data). This area consisted of a section of I-15 south of Temecula in a region of the freeway commonly referred to as the Santa Ana Mountains to Palomar Mountains Linkage (Figure 7).

Figure 7. Location map of Santa Ana to Palomar Mountains' Linkage area (red dotted lines upper center of map) relative to conserved (various ownerships), partially conserved (DOD, Native American Reservation, and I&WD), PAMA, and developed lands.
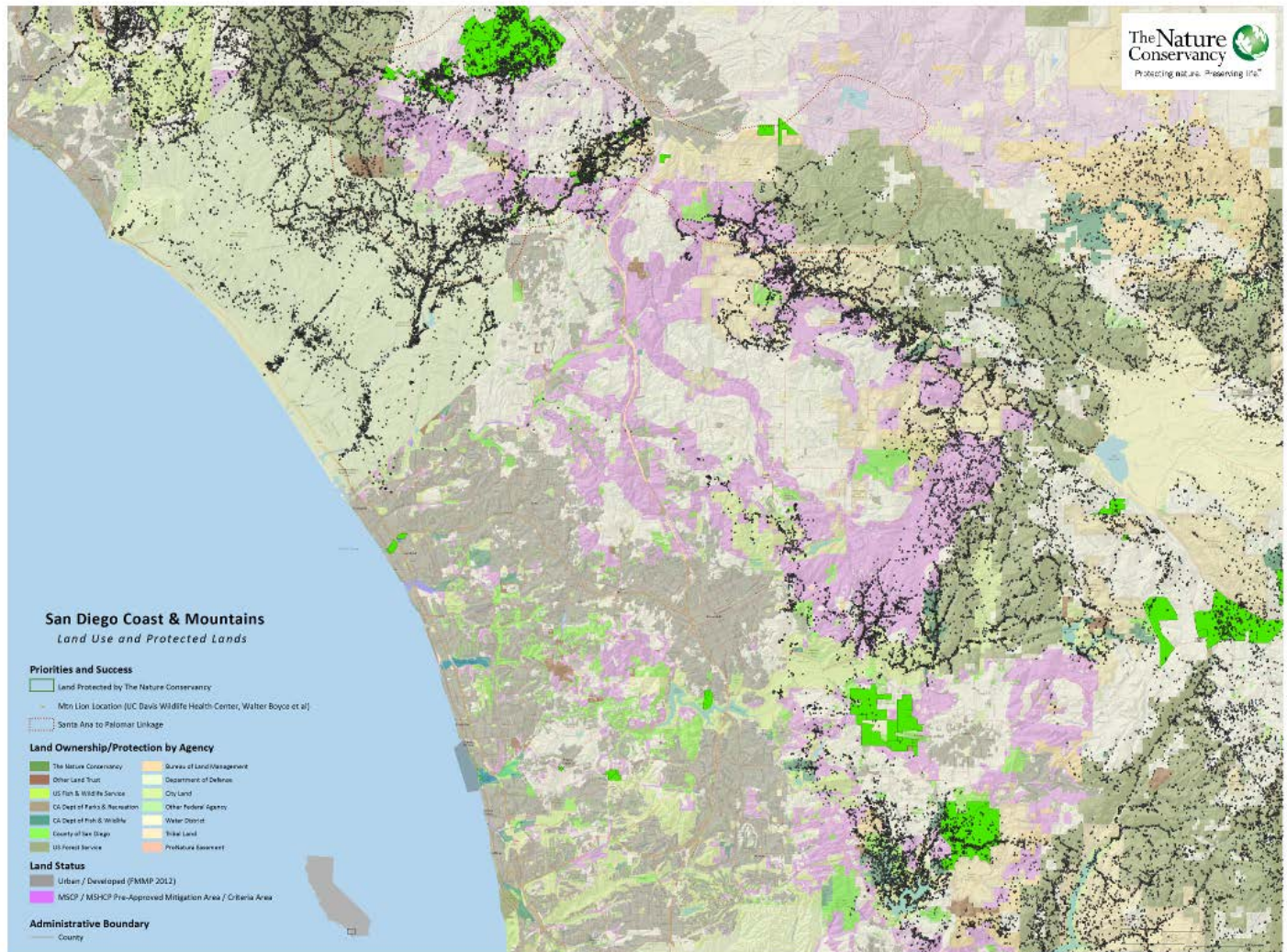
Eleven specific sites (Figure 8) that were evaluated for the placement of wildlife crossing infrastructure along I-15 were identified using several parameters that indicate potential use by wildlife if adequate crossing structures were present. These parameters were:

1. Current presence of suitable habitat or pathways that could be restored to wild habitat on both sides of the potential crossing;
2. Evidence from GPS-collars, camera traps, or other methods of close approaches of mountain lions or other carnivores (bobcats and coyotes) to the freeway at that location;
3. Indication in movement or corridor models that mountain lions and other wildlife are likely to approach or cross the roadway at that point;

4. Documented crossing by mountain lions or other wildlife at that location previously (either through existing structures or at grade);

5. Occurrence of mountain lion mortalities from roadkill at that location.

Figure 8. Eleven potential wildlife crossing points (1-8a, 8b-10) along a 6-mile stretch of I-15 in the Santa Ana Mountains to eastern Peninsular Range linkage area. Conserved lands are depicted in dark blue. View depicted is looking from the Palomar Mountains northwest up the Santa Ana Range with the Pacific Ocean to the west in the upper left corner.
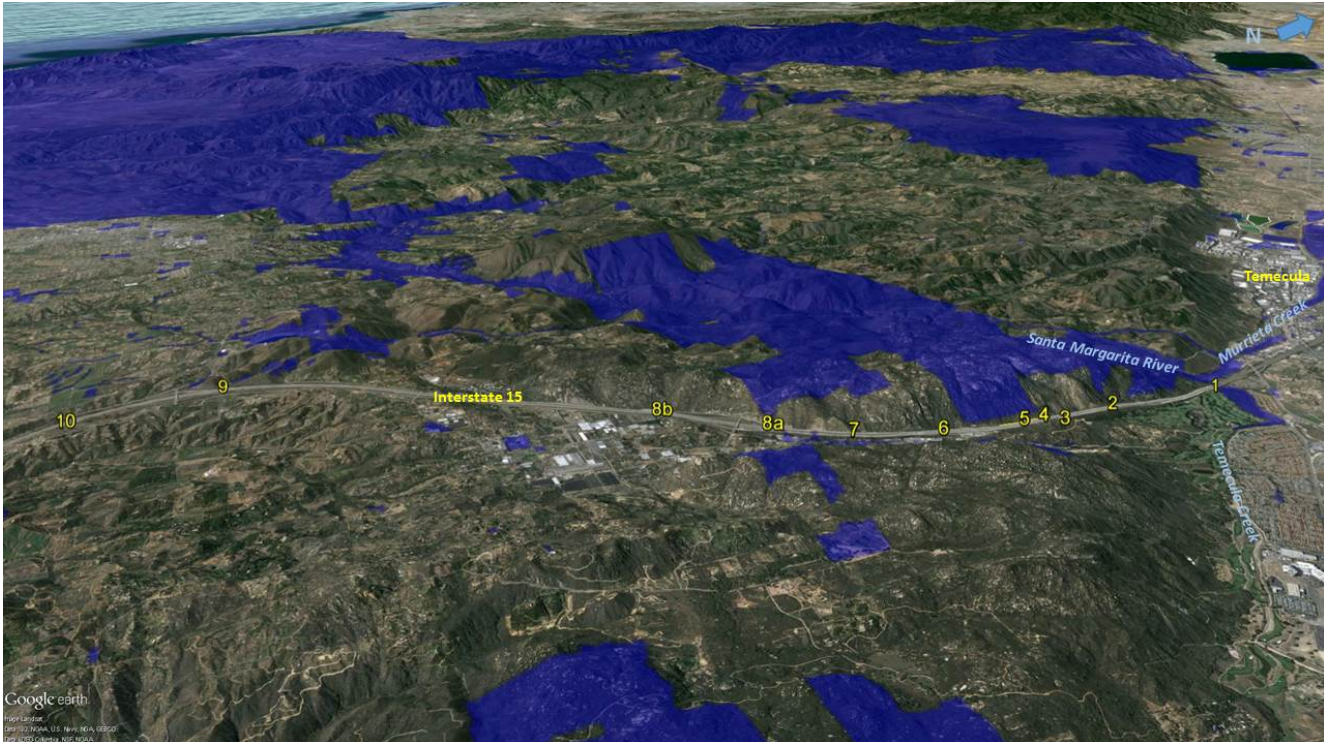
Scoring of each location for ranking purposes was accomplished in two methods, with equal weight in final rankings assigned to each method

Crossing Site Scoring - Method 1: Expert Opinion

Connectivity experts from around North America were assembled in January 2015 for a three-day workshop aimed at discussing, evaluating, and ranking locations and designs for infrastructure to improve connectivity (undercrossing, overcrossings, fencing, etc.) for I-15. The 101 Freeway was also part of the evaluation but those results are not presented here.

The panel of experts was provided with available information relating to the Santa Ana Mountains to eastern Peninsular Range linkage areas (aerial photos, maps, adjacent land conservation status, existing locations of culverts and bridges, data on crossing point use, modeling results, wildlife movement data) and participated in a day-long field tour of the linkage area to evaluate various sites for the placement of connectivity structures that had been identified through previous research. The field tour was then followed by an all-day workshop to discuss and rank sites and options for connectivity structures for each linkage. At this workshop, the experts

were joined by transportation planners, wildlife agency representatives, and various local connectivity experts who have been involved in past assessments of wildlife connectivity status and options at these locations.

During the all-day workshop, the invited experts were asked to rank the crossing point locations, and in many cases expressed their opinions relating to the likely best types of structures that could be utilized at those locations. Determining the most feasible or best type of structure that could be utilized at any particular crossing point was beyond the level of engineering expertise that was present at the workshop.

Rankings were converted into a point system that assigned a point score of 3 to each expert's first choice, a score of 2 to their second choice, and a score of 1 to their third choice. For the Santa Ana to Palomar Mountains Linkage I-15 crossing point assessments, some experts ranked more than one crossing point identically. In that case, both crossing points were given the same point score. Expert scores were then rescaled to a maximum score of 5 before combination with the categorical landscape and wildlife use rankings (also scaled to 5).

Crossing Site Scoring - Method 2 – Categorical Assessment of Landscape Characteristics and Wildlife Use

In this method, points were assigned to each wildlife crossing location based on important characteristics that were scored categorically (Appendix 1). Possible points for each characteristic ranged from 0-1 based on the strength of that characteristic at the site. In some instances, fractional scores were given to reflect partial satisfaction of the listed condition (e.g., for Landscape pattern - broad scale, if connectivity was present in 3 of 4 directions, this would generate a score of 0.75). The maximum number of points attainable by any individual site was 5 points. Rankings from each method were then added together to determine and compare overall rankings (maximum score of 10).

RESULTS

RESULTS - SANDAG Task 1 - Determine the locations within the study area where mountain lion movement is occurring for baiting and potential trapping, and documentation of habitat use

Cameras were placed and monitored in or near the NCMSCP during 2014 – 2015 in order to detect mountain lion movement for the purposes of locating potential capture sites, and for documentation of mountain lion presence. Data from all trail cameras our project has placed from 2015 to 2016 has been incorporated into the final database (Appendix 2). During that period, seventy-two trail cameras were active for 11,292 camera-nights, and mountain lions were photographed a total of 122 times at 11 camera stations (Figure 9; Appendix 1). In addition, photos of over 20 other wildlife species were captured a total of 5,369 times.   In the 2013 – 2014 study of core conserved areas in the western portion of the county, mountain lions were photographed a total of 141 times in 24,009 nights of camera monitoring, and other wild animals were photographed over 11,000 times (Appendix 3).

Figure 9. Map with locations noted where trail cameras (camera symbols) were placed during 2013-2014 and 2015-2016 study periods. Many locations have multiple cameras present. The NCMSCP is outlined in green. Red camera symbols represent locations where mountain lions were detected, blue camera symbols represent locations where mountain lions were not detected.

RESULTS - SANDAG Tasks 2 and 3 – Capture and GPS collar mountain lions in the NCMSCP; Download data from GPS collars and record mortalities in the study area.

Beginning in February 2015, 6 mountain lions were captured, sampled, and GPS collared a total of 9 times in the study area (Table 2). Data from 2 additional animals that were collared 3 times in 2013-2014 and circulated in the NCMSCP during this study period were included in the study dataset. Full data sets were retrieved from 11 of the 14 total collars placed on these individuals, and partial data sets from 3 collars. Details relating to the individual animals that circulated in the study area during the 2014 – 2015 period are listed in Table 2.

In addition, data retrieved from mountain lions collared as part of the previous SANDAG-sponsored study (2013-2014), and other UCD studies in the San Diego County (n = 44), are incorporated in this report.   Data from GPS-collared mountain lions in adjacent areas of Riverside and Orange Counties were also utilized in some analyses. GPS locations were collected at 5 – 15 minute intervals from a subset of the collared animals, which has allowed movement patterns to be analyzed at fine scales by Dr. Zeller (see CDFW-LAG Tasks 1-5 results).

Table 2. Characteristics of mountain lions using portions of the current study area during the study period February 2015 – December 2016.

Animal ID	Date captured / recaptured	Gender	Last Known Status
M109*	4/1/13; 4/3/14	M	Deceased
M125**	3/18/14	M	Alive as of 3/4/17 (photo)
F137*	2/26/15; 4/29/15;12/17/15	F	Alive as of 3/18/16 (collar dropped)
F138**	2/26/15; 4/29/15	F	Alive as of 1/18/16 (photo)
F139*	2/26/15; 12/17/15	F	Alive as 3/18/16 (collar dropped)
M32*	5/23/05; 9/16/15	M	Deceased
M145*	12/7/15	M	Alive as of 6/14/16 (collar dropped)
M146**	1/19/16	M	Alive as of 7/12/16 (collar data)

*All data recovered from collars after mortality or collars dropped
** Partial data received from transmission to satellites – full data sets will be obtained when / if collars recovered. F138's collar dropped after apparent VHF transmitter malfunction, and it has not been located for recovery to date. M125's collar is still present on the animal based on recent photographs from trail cameras.

Mountain lion capture and mortality locations in San Diego County and the NCMSCP specifically are depicted in Figure 10.   These locations included all mountain lion captures that resulted in GPS-collar placement on the animal from the beginning of the UCD study in 2001 to the present. Mortality locations are those that were documented either by the research team or Randy Botta and Janene Colby of CDFW from 1986 – 2016 (Vickers et al. 2015, Vickers et al. unpublished data). The long-term (30-year) mortality data set allows comparisons between where mountain lions have been known to exist previously and where they have currently been detected, as well as identification of areas where mountain lions may cluster due to various factors. For instance, areas of the Cuyamaca Mountains around Julian and Descanso appear to have higher levels of mortality from depredation permits than other parts of the County, both historically and more currently.

Figure 10 – Mountain lion mortality sites (red) and capture and GPS-collaring sites (yellow) in relation to the NCMSCP.
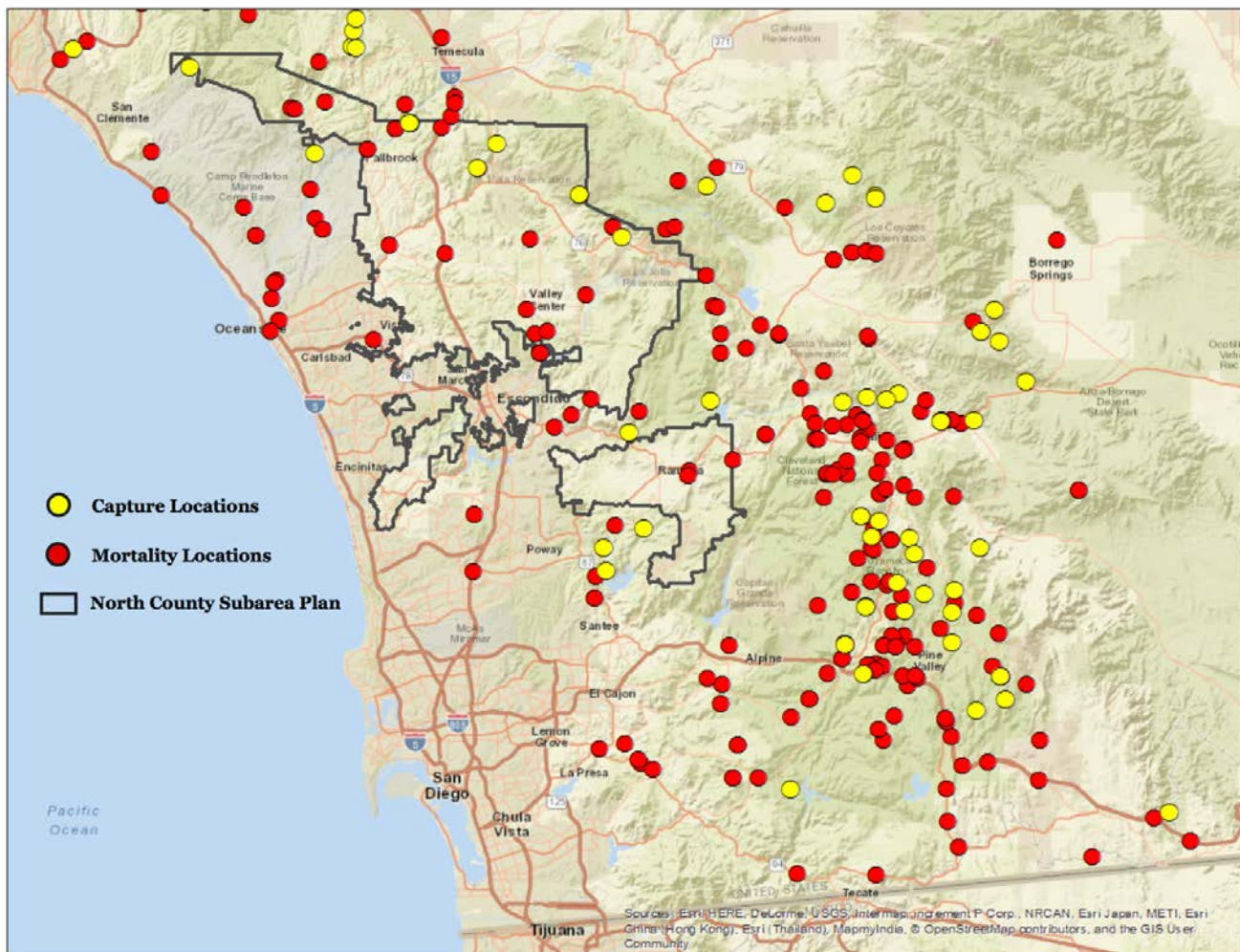
Mountain lion mortalities secondary to depredation permits in San Diego County continue to be almost exclusively males, suggesting that the potential for long distance gene movement within the region (which is primarily male-dependent) is being reduced secondary to this mortality source.

Specifically for dispersal age males (subadults less than 30 months of age) that are most likely to travel long distances and thus be the most important gene transfer agents, approximately half of all known mortalities within that demographic group (both GPS-collared and uncollared) in San Diego County between 2001-2016 were secondary to depredation permits, with vehicle collisions as the second most common cause of death for mountain lions as a whole in the county.

GPS-collared mountain lions have circulated throughout the conserved and un-conserved areas of San Diego County and adjacent areas of Riverside and Orange Counties (Figure 2) during the current study and the past studies by the research team. However, only one GPS-collared mountain lion has crossed I-15 between 2001 and 2016, and that individual crossed west to east and was killed on a depredation permit approximately three weeks later in southern San Diego County (Vickers et al. 2015).

Home Range Sizes Relative to Conserved Habitat

The individual mountain lions, their collar duration and the 100% and 90% kernel home range areas are provided in Table 3.

Table 3. Home range areas of individual mountain lions with 90% and 100% Home Range Kernel Areas

	Mountain Lion	Collar duration (months)	100% Home Range Kernel Area	90% Home Range Kernel Area
Females	F105	12	176km²	131km²
	F121b	8	96km²	77km²
	F137	6	141km²	85km²
	F28	13	453km²	356km²
	F29	7	125km²	101km²
	F35	12	476km²	341km²
	F38	16	434km²	309km²
	F45	10	487km²	397km²
	F47	28	427km²	341km²
	F49	16	257km²	197km²
	F50	11	98km²	66km²
	F51	10	201km²	153km²
	F52	6	153km²	110km²
	F55	22	182km²	144km²
	F61	9	195km²	131km²
	F90b	7	207km²	149km²
	F92b	7	51km²	41km²
	F95	32	492km²	379km²
	F126	7	213km²	165km²
Males	M106	12	620km²	366km²
	M107	10	478km²	352km²
	M109	12	579km²	436km²
	M119	5	408km²	309km²
	M125	5	521km²	302km²
	M17	5	1141 km²	964 km²
	M31	5	162km²	90km²
	M59	6	435km²	287km²
	M64	13	609km²	432km²
	M67	10	665km²	497km²
	M91	5	105km²	89km²

The mean home range size across all mountain lions was 260km² (100 square miles) while the mean for females was 193km² (75 square miles) and the mean for males was 375km² (145 square miles). 90% home range polygons for males and females are shown in Figures 11 and 12.

These home range sizes are far larger than almost any conserved core habitat area in the NCMSCP and other conserved habitat areas of San Diego County except for the national forest lands in the eastern Peninsular Range, and Anza Borrego and Cuyamaca Rancho State Parks. Thus, territorial mountain lions have to travel between conserved habitat areas regularly in order to survive. Currently, mountain lions do not have adequate protected corridors to allow relatively safe travel between conserved habitat areas in the NCMSCP and the

larger region. Even with conserved corridors these territory sizes dictate the necessity for many road crossings for most mountain lions (See road crossing analyses below). Both travel across un-conserved lands and road crossings put mountain lions at increased risk from human-associated mortality causes.

Figure 11. Male mountain lion 90% home range polygons displayed with currently protected and partially protected (Department of Defense, Native American Reservation) lands.

Figure 12. Female mountain lion 90% home range polygons displayed with currently protected and partially protected (Department of Defense, Native American Reservation) lands.
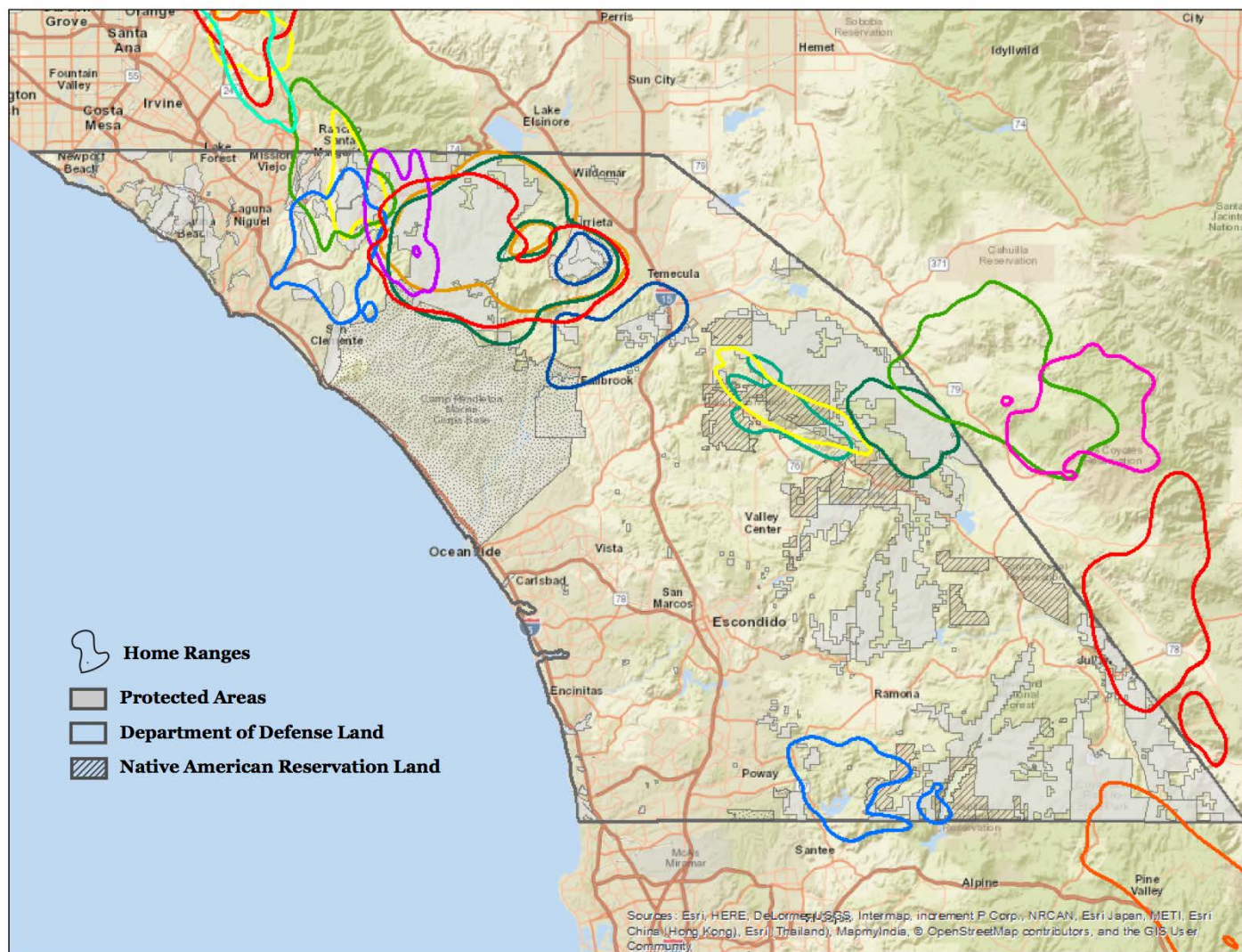
RESULTS - SANDAG Task 4 - DNA isolation and genotyping with genetic analysis and pedigree and family relationship reconstruction. Transmit genetic data to Dr. Kathy Zeller (See CDFW-LAG funded Task List below) for landscape genetics analysis.

As noted in the Methods section, a broad array of analytical tools were used to thoroughly characterize the genetic status of the mountain lion populations in the region, and to create pedigrees for as many individuals as possible.

These analyses (via population assignment) confirmed earlier findings that the Santa Ana Mountains and Eastern Peninsular Range mountain lion populations are highly differentiated from each other, suggesting that barrier effects to gene flow across I-15 are substantial.

The barriers to gene flow across I-15, especially into the Santa Ana Mountains from the east, had been characterized in Ernest et al. (2014) as having resulted in serious genetic restriction in the Santa Anas population. This finding was generally re-confirmed in this analysis. Population assignment suggested that there may have been five additional animals whose genetic origins were on opposite sides of I-15 from where they were sampled, implying a crossing event had occurred. However, no offspring from these individuals were detected.

One individual (M86) was identified previously as being likely to have originated east of I-15 and to have crossed into the Santa Anas and reproduced (Ernest et al. 2014, Vickers et al. 2015), though M86 was later killed by a vehicle (Vickers et al. unpublished data). This current analysis has indicated that M86 had additional offspring that were not identified in the previous analysis, and though many of those likely offspring are also deceased from common causes of mortality such as vehicle strikes and depredation permits, M86 may have had a positive effect on the genetic diversity in the Santa Ana population and reduced the genetic differences between the Santa Ana and Eastern Peninsular Range populations.

Although the Eastern Peninsular Range population appears to have moderate levels of genetic diversity, a separate and preliminary statewide mountain lion population genetic study (Gustafson, Ernest, in prep) indicates the Eastern Peninsular Range population might also be isolated from other mountain lion populations in California. The most immediate interstate appearing to isolate the Eastern Peninsular Range is I-10, just south of the San Bernardino and San Gabriel Mountains. This is further supported by the population assignments, which indicated mountain lions in the San Gabriel and San Bernardino Mountains are distinct from the Eastern Peninsular Range and Santa Ana mountain lions. It is possible, however, that the Eastern Peninsular Range population is genetically connected to mountain lions in Mexico and/or Arizona. Further research is needed to evaluate the extent to which the Eastern Peninsular Range population is isolated from currently unsampled populations.

Other family pedigrees were constructed and close familial relationships defined where possible (Figure 13). These pedigrees illuminated the mating activities and specific likely offspring of numerous other animals in both the Santa Ana and Eastern Peninsular Range populations. The pedigree construction indicated that first order (parent–offspring or full-sib) relationships of some type were identifiable for approximately 80% of the

animals sampled. This pedigree construction indicated that there were likely matings between parents and offspring on several occasions in both the Santa Anas and Eastern Peninsular populations.

Combined, GPS data and genetic analyses (including pedigree analyses) indicate that physical and gene movement is occurring between MU's 4 and 5, and the eastern halves of MU's 6 and 8 in the MSPA, as well as elsewhere in the region on either side of I-15. Some physical movement has occurred across I-15 in both directions during the period of the study, but only one instance of gene transfer has been documented via detection of offspring of those animals.Estimates of effective population sizes did not differ from those published previously (Ernest et al. 2014) with Santa Ana at 5.1 (95% CI: 3.3–6.7) and Eastern Peninsular Range at 24.3 (21.7–27.3).

Overall genetic diversity – All positive measures associated with genetic diversity (number of alleles, heterozygosity, Shannon index) were lower in the Santa Anas than the Eastern Peninsular Range. In contrast, all negative measures (inbreeding coefficients, internal relatedness) were higher for Santa Ana mountain lions than Eastern Peninsular Range mountain lions. This indicates the Eastern Peninsular Range population has greater genetic health than the Santa Ana Mountains population. However, there is concern on the research team's part that given the lack of evidence of connection of the southern Riverside, Orange, and San Diego counties' population with those further north, that further erosion of any still existent connectivity with populations to the south and east would at some point threaten the genetic health of this population similarly to the subset of the population in the Santa Ana Mountains.
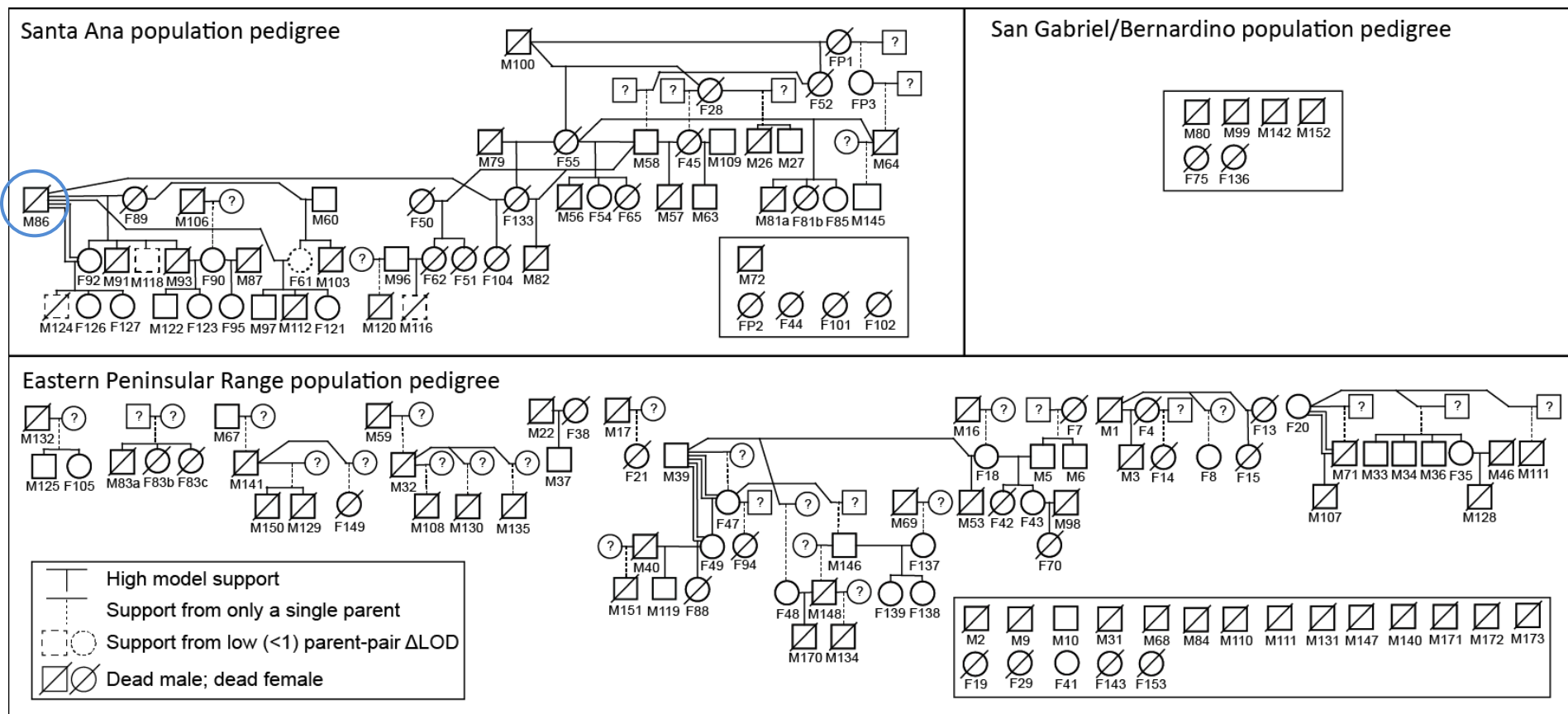
Figure 13. Estimates of relationships using microsatellite data from mountain lions sampled in the Santa Ana (n = 56), San Gabriel/Bernardino (n = 6), and Eastern Peninsular (n = 84) Ranges mountain lions. Analyses are based on 44 microsatellite loci and several software programs. Results could change (usually minor but possibly more significant) when subjected to peer review or when compared with pending/different analyses being conducted under other funding sources with other collaborators. Precision of molecular pedigree reconstruction (making family trees using DNA data) depends on a number of factors including amount of DNA data available and percentage of all possible parents present in the sample set. With mountain lions, the percentage of all possible parents are represented in the sample set is unknown, but likely higher in Santa Ana's than Eastern Peninsular Range (more open habitat, larger area than Santa Ana habitat). Other new and in-progress genetic research in the Ernest Lab being conducted on mountain lions in this area include the use of high density single nucleotide polymorphism (SNP) data sets. SNPs may provide more detailed data for understanding mountain lion connectedness, relatedness, and familial relationships. Also, when additional mountain lion samples (especially additional potential parents) are analyzed in the future, changes in the pedigree may result. Dashed lines represent parent–offspring support from only a single parent. Not knowing the other parent adds uncertainty to the relationship. Dashed lines around individuals indicates support from a low change in likelihood ratio (ΔLOD). A low ΔLOD adds uncertainty to the relationship. M86 circled in upper left corner.

RESULTS – CDFW-LAG Task 1: Perform a resource selection function analysis and identify critical resource use patches for mountain lion across the study area.

The univariate Home Range Selection Functions (HRSF) revealed that mountain lions select for environmental variables at mostly coarse scales when selecting a home range (Table 4). Due to convergence errors, we were unable to fit the model for primary roads. We found mountain lions prefer higher elevations, more topographic relief, and all natural land cover types with the exception of deserts when selecting home ranges. Furthermore, mountain lions avoided all urban, roaded, and agricultural areas when selecting home ranges.

After removing correlated variables, the top HRSF model included the following variables: terrain ruggedness, agriculture, barren, chaparral, coastal oak woodland, coastal scrub, desert, grassland, and urban.

The univariate Point Selection Functions (PSFs) indicated mountain lions have a mostly bi-modal scaling response to landscape features when operating at the within home range level (Table 4). Mountain lions responded to elevation, percent slope, chaparral, and coastal scrub at fine scales and responded to the other variables at coarse scales. Due to convergence errors, we were unable to fit the models for desert and primary roads.

Similar to the HRSFs, we found mountain lions in the study area avoided areas of human development. However for the PSFs, mountain lions avoided higher elevation areas and steeper slopes while slightly preferring areas that were more rugged. Land cover types that were preferred in the PSF models included coastal oak woodland and riparian areas. Land cover types that were avoided included agriculture, chaparral, coastal scrub, grassland, and barren areas (Table 4).

After removing correlated variables, the global PSF model was identified as the top model. This model included the following variables: elevation, percent slope, terrain ruggedness, agriculture, barren areas, chaparral, coastal scrub, grassland, riparian, coastal oak woodland, urban, and roads represented as primary, secondary, and tertiary roads.

Table 4. Standardized beta coefficients and characteristic scales of selection for each predictor variable as identified through the univariate Home Range Selection Functions and Point Selection Functions. Empty cells indicate model convergence errors.

	Variable	Home Range Selection Function		Point Selection Function	
		Beta Coefficient	Characteristic Scale	Beta Coefficient	Characteristic Scale
Topo-graphic	Elevation	0.209	2000 m	-35.20	241m
	Percent Slope	1.102	8000 m	-1.36	241m
	Terrain Ruggedness	1.095	10000 m	0.198	4461m
Land cover Type	Agriculture	-0.166	6000 m	-0.489	4461m
	Chaparral	0.630	4000 m	-0.502	241m
	Coastal Scrub	0.083	500 m	-0.291	681m
	Coastal Oak Woodland	0.304	10000 m	0.467	4461m
	Grassland	0.297	10000 m	-0.332	4461m
	Barren/Open Water	0.175	4000 m	-0.065	3994m
	Desert	-0.905	8000 m	-	-
	Riparian	0.235	10000 m	0.386	3497m
Human Development	Urban; Classified as High, Medium, and Low density Urban Areas	-0.798	2000 m	-2.598	4461m
	Roads; Classified as Primary, Secondary, and Tertiary	-0.634	10000 m	-0.254	4461m
	Roads; Classified as Primary, and Secondary	-0.439	6000 m	-4.129	4461m
	Roads; Primary only	-	-	-	-

The hierarchically integrated predicted probability of resource use surface is provided in Figure 14 and the final resource use patches are provided in Figure 15, with zoomed in views in Figures 15a,b,c (Appendix 4). The resource use patches measure 2,577km^2 (995 sq. miles) in total.

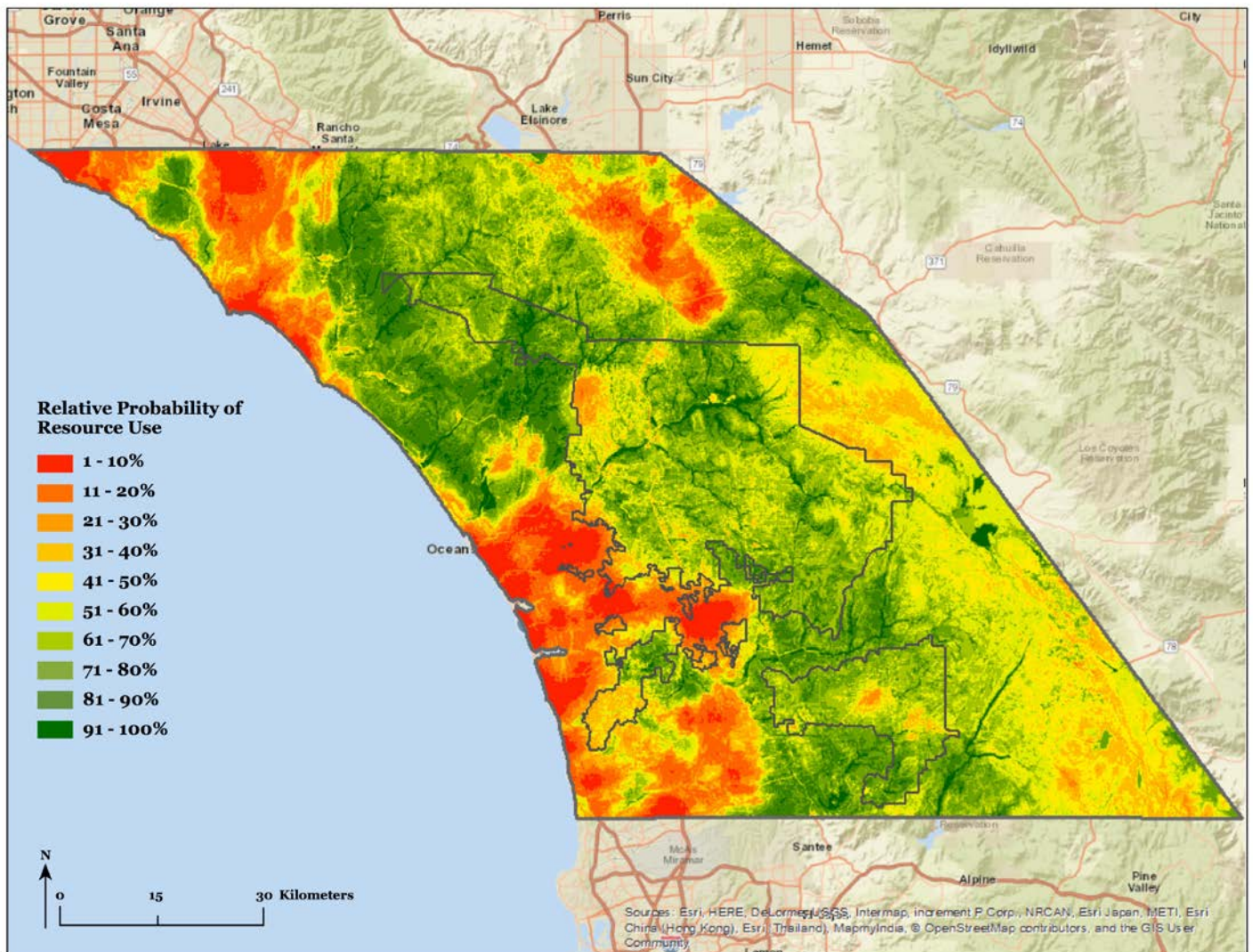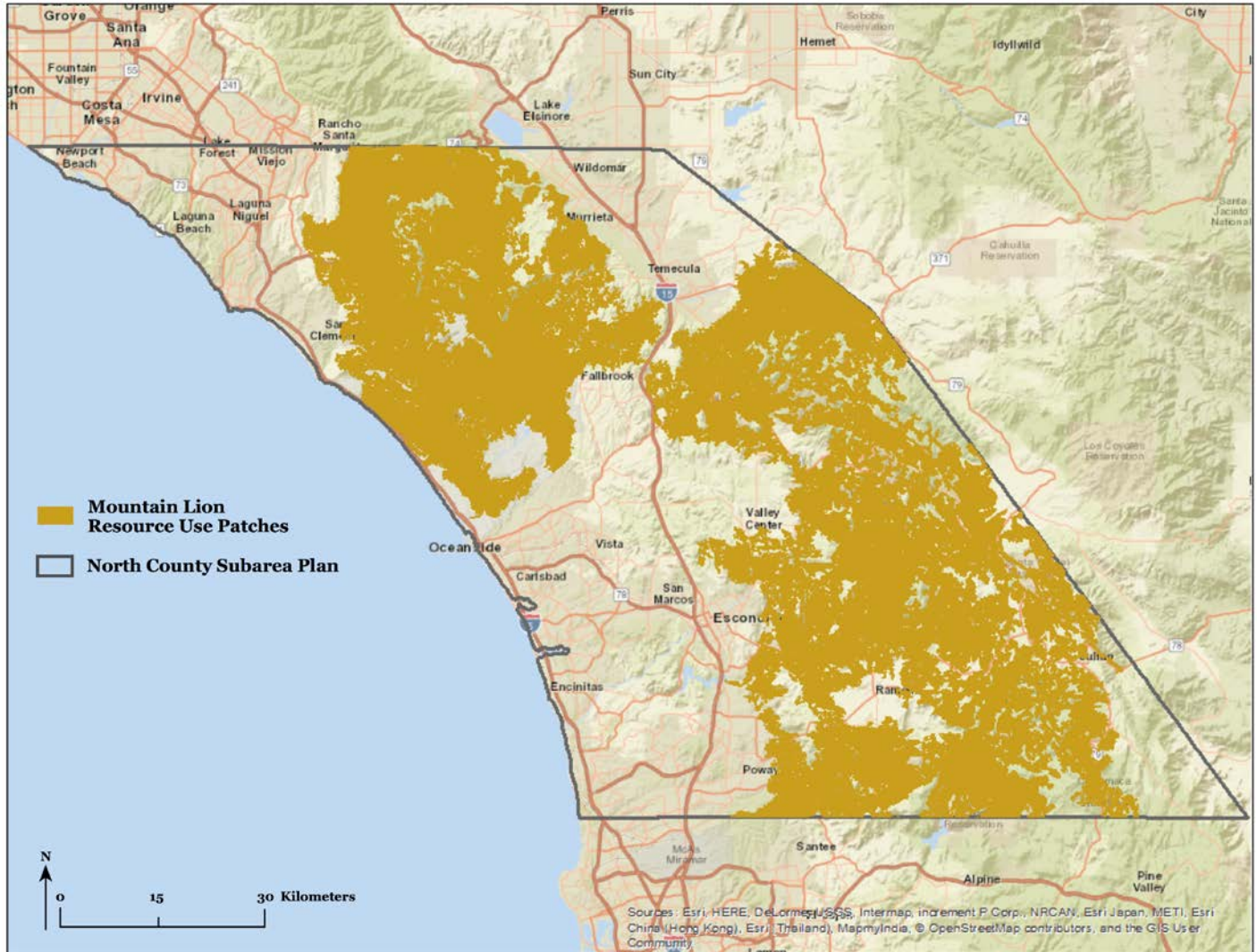**Figure 14. Hierarchically integrated predicted probability of resource use surface.**

Figure 15. Resource Use Patches greater than 50km^2 derived from relative probability of use surface.

RESULTS - CDFW-LAG Task 2 - Perform a movement selection function analysis to estimate probabilities of movement across the study area.

Mountain lions selected for landscape variables at a wider range of scales during movement (Table 5) than during resource selection events (Table 4). During movement events, mountain lions tended to avoid all areas of human development. Mountain lions also avoided steep slopes, but preferred higher elevations and more rugged terrain. Areas with coastal scrub, coastal oak woodland, and riparian facilitated movement, while areas with agriculture, chaparral, grassland and barren impeded movement (Table 5).

After removing correlated variables, four top models were identified and beta coefficients were averaged. The final model included: Elevation, percent slope, agriculture, barren, chaparral, coastal oak woodland, grassland, riparian, urban, and roads represented as primary, secondary, and tertiary roads.

Table 5. Standardized beta coefficients, standard errors and characteristic scales of selection for each predictor variable as identified through the univariate Movement Selection Function analysis.

	Variable	Beta Coefficient	Standard Error	Characteristic Scale
Topo-graphic	Elevation	6.47	0.37	241m
	Percent Slope	-1.151	0.116	2797m
	Terrain Ruggedness	1.174	0.083	681m
Land cover Type	Agriculture	-1.104	0.433	3819m
	Chaparral	-0.389	0.073	3104m
	Coastal Scrub	0.56	0.076	241m
	Coastal Oak Woodland	3.228	0.214	241m
	Grassland	-0.671	0.174	2797m
	Barren/Open Water	-0.269	0.127	3104m
	Desert	-	-	-
	Riparian	1.836	0.115	1317m
Human Development	Urban; Classified as High, Medium, and Low density Urban Areas	-7.58	1.447	241m
	Roads; Classified as Primary, Secondary, and Tertiary	-0.745	0.088	3819m
	Roads; Classified as Primary, and Secondary	-1.144	0.4456	4461m
	Roads; Classified as Primary	-	-	-

The predicted probability of movement surface is provided in Figure16, with zoomed in views in Figures 16a,b,c (Appendix 4).

Figure 16. Relative probability of mountain lion movement.
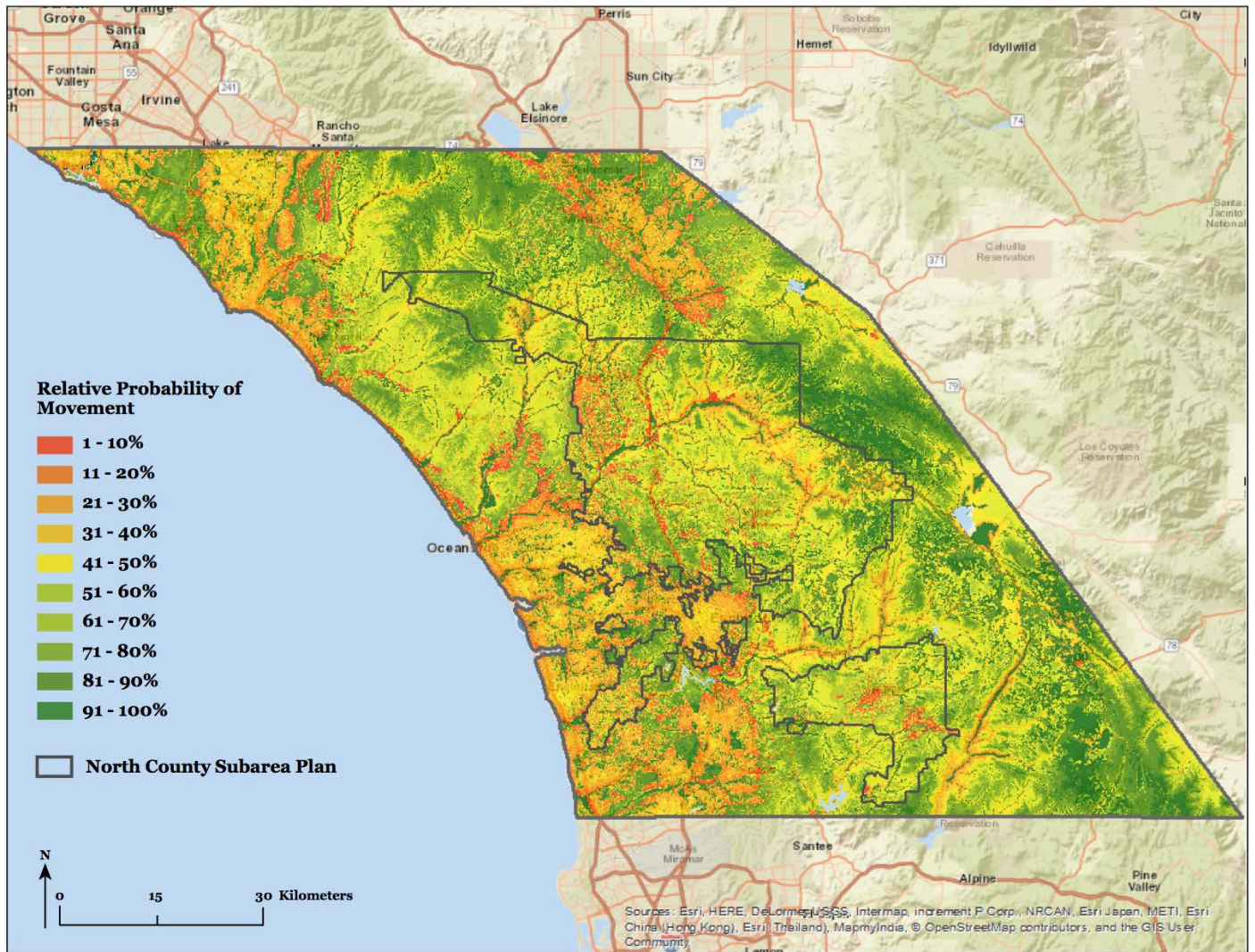
RESULTS - CDFW-LAG Task 4 - Use genetic data in a landscape genetics analysis to estimate mountain lion resistance to movement. The correlation between this resistance surface and that of the GPS-derived surface will help to identify and flesh out any potential gaps in the connectivity analysis.

The linear mixed effect models resulted in identifying the characteristic scale and transformation for each variable in relation to the genetic distances among individuals (Table 6). Selected variables whose resistance increased with increasing values were agriculture, grassland, urban, and roads. Selected variables whose resistance decreased with increasing values were chaparral, percent slope, riparian, coastal scrub, and coastal oak woodland. Resistance for elevation and ruggedness were represented by an Inverse Ricker transformation, which decreases until middle values were reached and then increased for the remaining values, indicating movement is facilitated at mid-elevation and mid-ruggedness values.

After accounting for correlations, the following variables were included in the multiple regression model: elevation, percent slope, agriculture, chaparral, coastal scrub, coastal oak woodland, grassland, riparian, urban, primary roads. The global model was selected as the best performing model with an AICc value of -20429. To determine whether the variables explained the genetic distance among individuals more than Euclidean distance alone, we also ran a regression model with a simple Euclidean distance matrix. This resulted in an AICc value of -20151, which was much higher than any other model, indicating the variables explained the genetic distance among variables better than distance alone.

Table 6. Characteristic scale and transformation to resistance as selected by model AICc values for each variable in the linear mixed effects model in relation to genetic distance.

	Variable	Transformation	Characteristic Scale
Topo-graphic	Elevation	Inverse Ricker	6000m
	Percent Slope	Negative Monomolecular Concave	100m
	Terrain Ruggedness	Inverse Ricker	500m
Land cover Type	Agriculture	Positive Linear	6000m
	Chaparral	Negative Monomolecular Concave	6000m
	Coastal Scrub	Negative Monomolecular Convex	500m
	Coastal Oak Woodland	Negative Monomolecular Convex	2000m
	Grassland	Positive Monomolecular Convex	500m
	Desert	Positive Monomolecular Concave	6000m
	Riparian	Negative Monomolecular Convex	500m
Human Development	Urban; Classified as High, Medium, and Low density Urban Areas	Positive Monomolecular Convex	500m
	Roads; Classified as Primary, Secondary, and Tertiary	Positive Monomolecular Convex	500m
	Roads; Classified as Primary, and Secondary	Positive Linear	2000m
	Roads; Primary only	Positive Monomolecular Convex	500m

The final resistance surface from the landscape genetic analysis is provided in Figure 17, with zoomed in views in Figures 17a,b,c (Appendix 4). The correlation between the landscape genetic resistance surface and the MSF resistance surface was 0.3. Though coarse patterns are similar between the two surfaces, the finer detail of the MSF surface was not represented in the landscape genetic surface, resulting in a fairly low correlation between

the surfaces. Ultimately, we wanted not only to be sure we captured fine scaled movement patterns for mountain lions across the study area, but also coarse scale movement that results in the exchange of genetic material. Therefore, we used the integrated resistance surface presented in the next section.

Figure 17. Resistance surface from landscape genetic analysis.
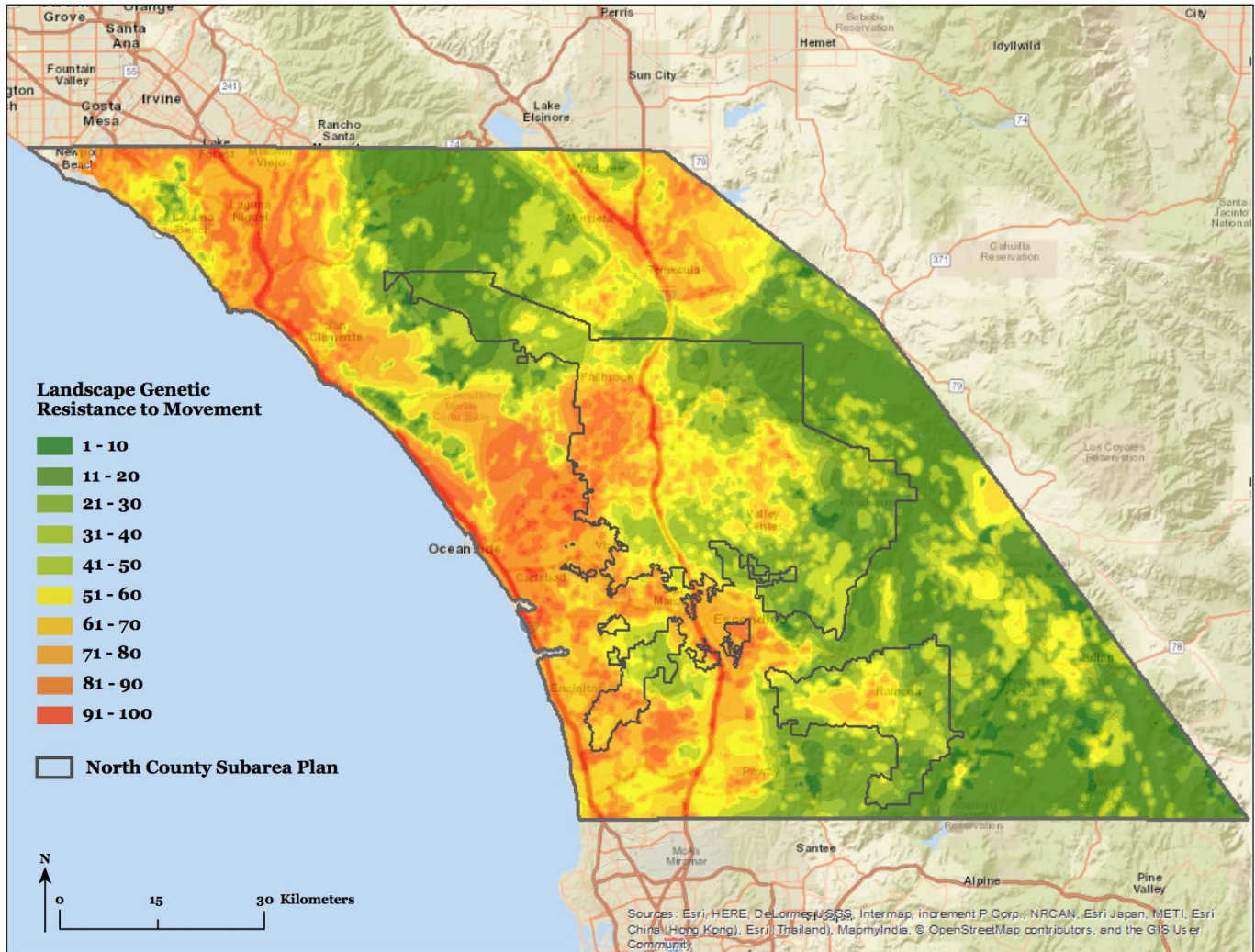
RESULTS - CDFW-LAG Task 3 - Identify mountain lion connectivity across the study area by modeling two types of corridors, Factorial Least-Cost Paths (FLCP's) and Resistant Kernels. Factorial Least-Cost Paths combined with mountain lion GPS paths locations will identify potential road crossing locations. Landscape level connectivity will be identified with resistant kernels.

Results of the FLCP analysis are provided in Figure 18, with zoomed in views in Figures 18a,b,c (Appendix 4).

Figure18. Factorial Least Cost Path results displayed as the added number of paths per pixel. This represents the cumulative number of least cost paths among all pairwise least-cost paths that cross each pixel. Only pixels with at least 100 least-cost paths are shown.
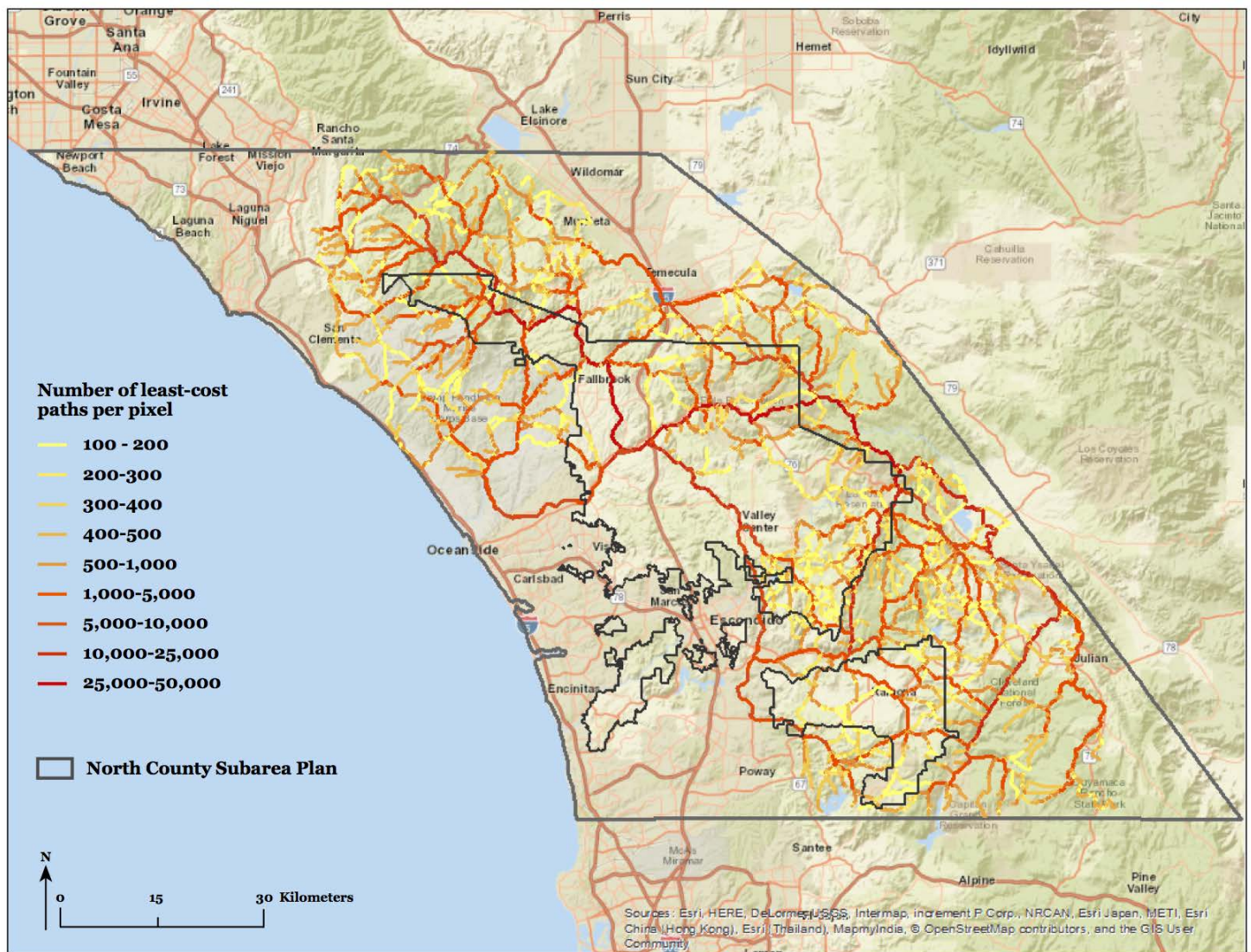
Road crossing locations with at least 100 paths are shown in Figure 19, with zoomed in views in Figures 19a,b,c (Appendix 4). Crossing locations were identified only on primary and secondary roads of interest. We also display the crossing locations from mountain lions with 5-min and 15-min GPS telemetry data and these observations represent a very small subset of all recorded crossings. We used only the 5-min and 15-min data here as these data allow a relatively accurate crossing location to be identified. It is notable that though FLCP analysis identified several potential I-15 crossing points, only two are at locations where large structures exist (bridges) that allow safe mountain lion passage currently – the Temecula Creek Bridge and San Luis Rey River Bridge, both also identified as corridor crossing points in corridor modeling described elsewhere in the report. Several major highways in and around the NCMSCP were identified as having numerous crossing points, including SR's 76, 78, 79, 67, Pala-Temecula Rd., and Wildcat Canyon / Barona Rd.

Figure19. Probable road crossing locations for mountain lions as identified through the FLCP analysis along with actual crossing locations by mountain lions. Note: Crossings were only identified on primary and secondary roads of interest, and only data from mountain lions with 5-min and 15-min data were used to define actual crossing points.
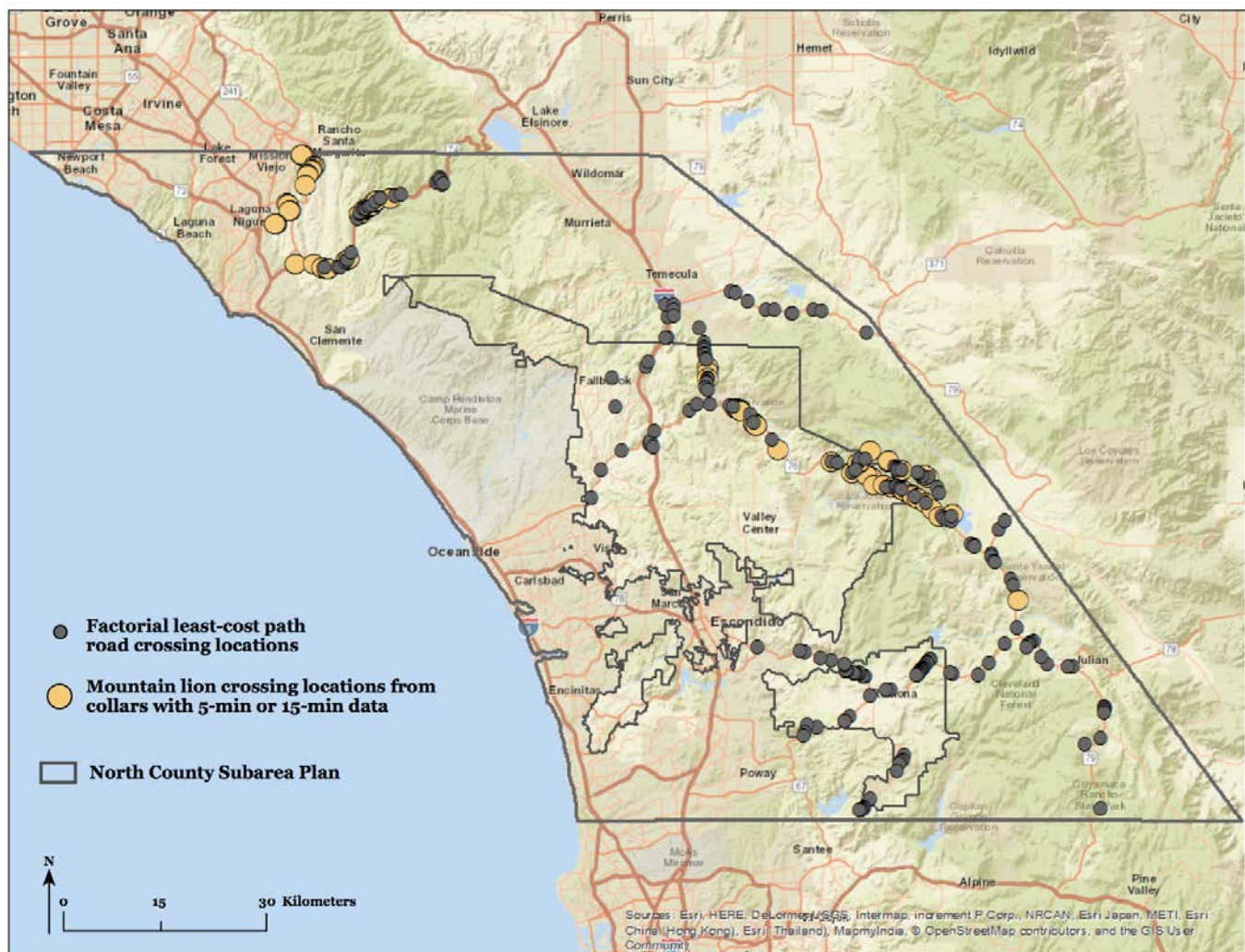
Actual Road crossings by GPS-collared mountain lions in San Diego County
The total number of GPS-collared mountain lions that had all or part of their paths in San Diego County was 66 (35M, 31F). Of that number, 51 (35M, 16F) crossed many of the busiest highways in northern San Diego County a total of 1,540 times while wearing GPS collars (2001-2016). GPS-collared females have in some cases been accompanied by kittens during their crossings, so the total number of individual crossings associated with GPS-documented crossings is higher. Certainly GPS-collared mountain lions also crossed many of these same highways before being GPS-collared and after their collars dropped off. In addition, many un-collared mountain lions no doubt crossed San Diego County highways during this period.

The data from the GPS-collared mountain lions represent successful crossings; however, 6 GPS-collared mountain lions have been killed in San Diego County while crossing roads during the period 2001 - 2016, and at least two were apparently struck but did not die, though one was euthanized later. Twenty-five un-collared mountain lions are known to have been killed while crossing roads during this same period. The phenomenon of animals being struck by vehicles but not dying on the roadway or shoulder suggests that a number of vehicle-related deaths have possibly occurred that were not discovered and are not in our data. Crossings of minor roads and streets were not included in Table 7, though mountain lions are sometimes also killed on these less busy thoroughfares.

A summary of which major roads were crossed by the 51 GPS-collared mountain lions is provided in Table 7.

Table 7.   Crossings of major roads by 51 GPS-collared mountain lions

Hwy	Male	Female	Total
I-15	1	0	1
SR 79	568	336	904
SR 78	188	195	383
SR 76	35	12	47
SR 67	29	0	29
S 6 and 7	108	0	108
Wildcat Cyn/Barona Rd	49	6	55
Pala-Temecula Rd	0	12	12
Old Castle Rd	1	0	1
Total	**979**	**561**	**1,540**

Corridors (Figure 20) were derived from the resistant kernel analysis utilizing the integrated MSF and landscape genetics resistance surfaces, with zoomed in views in Figures 20a,b,c (Appendix 4). Several corridors were identified that crossed I-15, though only two, the Temecula Creek Bridge and San Luis Rey River Bridge are currently viable and safe options for mountain lions crossing this interstate. Only the Temecula Creek Bridge provides safe passage between major habitat cores east and west of I-15 that are in immediate proximity to the freeway.

Though the San Luis Rey River channel provides conserved habitat on either side of that bridge, the corridor

becomes much more constricted as it proceeds west, and is not continuous with large cores of habitat to the north.

Figure 20. Mountain lion corridors derived from resistant kernel analysis utilizing the integrated MSF and landscape genetics resistance surfaces. Corridors were identified as the top 25% of the resistant kernel surface.

RESULTS - CDFW-LAG Task 5 – Use resource use patches, corridors, and road crossing locations to identify a conservation network for mountain lions in the study area and provide a prioritization framework for conservation and road crossing improvements

To determine how well represented resource use (RU) patches were across the study area, we overlaid the RU patches with conserved areas and military lands (Figure 21, with zoomed in views in Figures 21a,b,c - Appendix 4). The current conserved (protected) areas cover large areas of RU patches, but also omit key areas. The protected area network captures 35% of the patches, while partially protected lands such as Department of Defense (DOD) lands capture 15% of the patches, Irrigation and Water District (I&WD) lands capture 2% of the patches, and Native American Reservation lands capture 9% of the patches (Table 8). This leaves 39% (1004 km^2) of the RU patches, on privately held (unprotected) lands.

Figure 21. Mountain lion resource use patches and currently protected or partially protected (DOD, Native American Reservation, and I&WD) lands. Resource use patches outside of currently protected or partially protected lands are depicted in yellow.
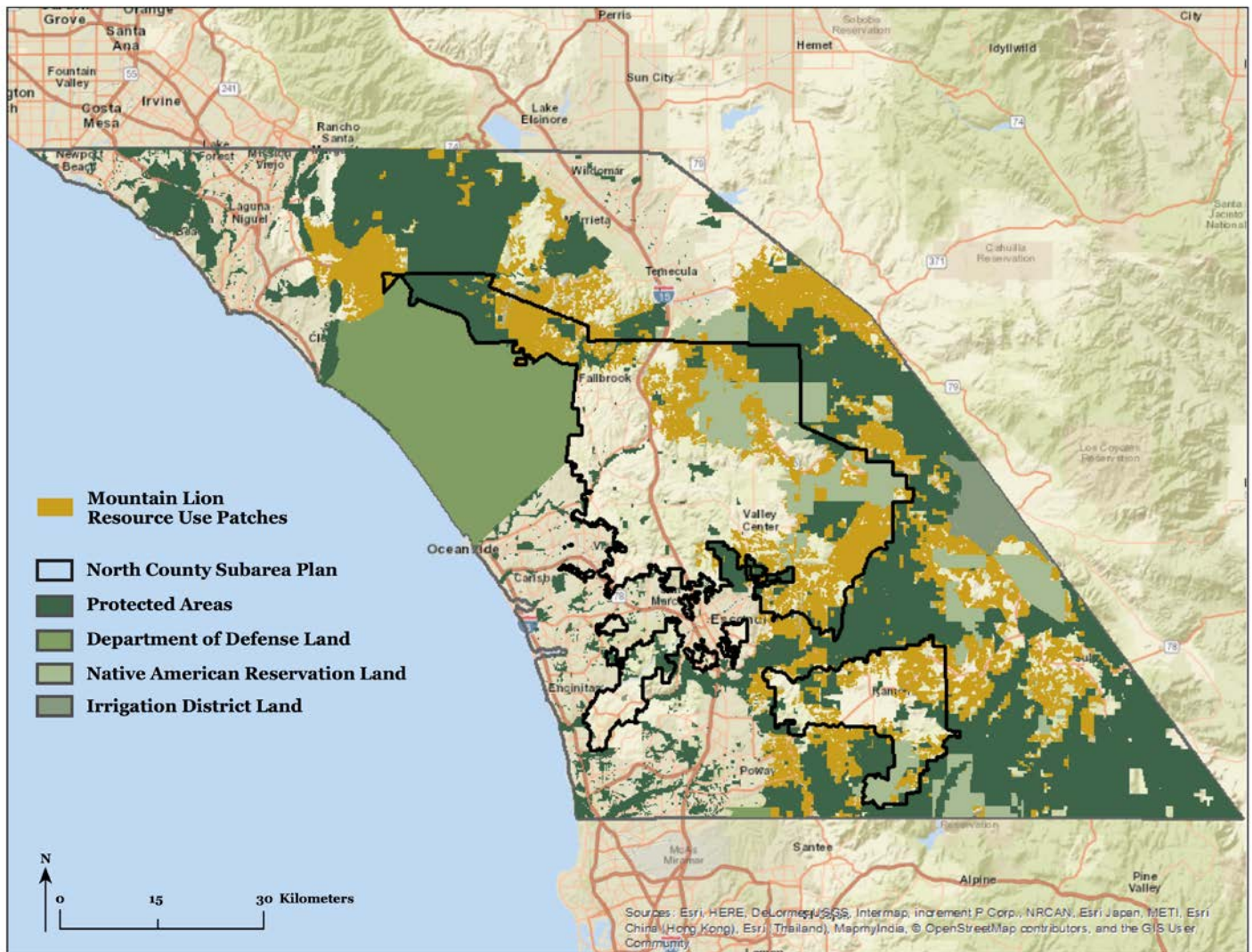
Table 8 – Percentages and land area (km²) of modeled RU patches, and corridors outside of RU patches, that are on protected, partially protected, and private lands.

Modeled area	Fully protected		Partially protected		Privately held as of March 2017	
	Percent	Km²	Percent	Km²	Percent	Km²
Resource use (RU) patches (2,577 Km²)	35%	897	26%	676	39%	1,004
Corridor areas outside of RU patches (777 Km²)	47%	368	12%	97	41%	312

By including the proposed protected areas (Pre-Approved Mitigation Areas – PAMA lands), a much greater percentage of the RU patches would be protected (Table 9, Figure 22). Inclusion of the PAMA lands (if protected at the 75% level, the San Diego County planning target), means that 62% of the RU patches would be fully protected with completion of the planned conservation network. The DOD, I&WD, and Native American Reservation lands capture another 26% of the RU patches (although those lands should be considered only partially protected). Thus a minimum of 12% of RU patches will still be unprotected once all conservation acquisitions currently planned are completed (Table 9). Figure 23, with zoomed in views in Figures 23e,f,g (Appendix 4) depicts the relationship of the RU patches to all protected, DOD, I&WD, Native American Reservation, and PAMA lands.

Table 9 - Percentages and land area (km²) of modeled RU patches, and corridors outside of RU patches, that are on protected, partially protected, and PAMA lands.

Modeled area	Proposed for protection (PAMA)		75% of PAMA		Fully Protected + 75% of PAMA		Fully protected + 75% of PAMA + Partially protected	
	Percent	Km²	Percent	Km²	Percent	Km²	Percent	Km²
Resource use (RU) patches (2,577 Km²)	36%	927	27%	695	62%	1,592	88%	2,268
Corridor areas outside of RU patches (777 Km²)	29%	225	22%	169	69%	537	82%	634

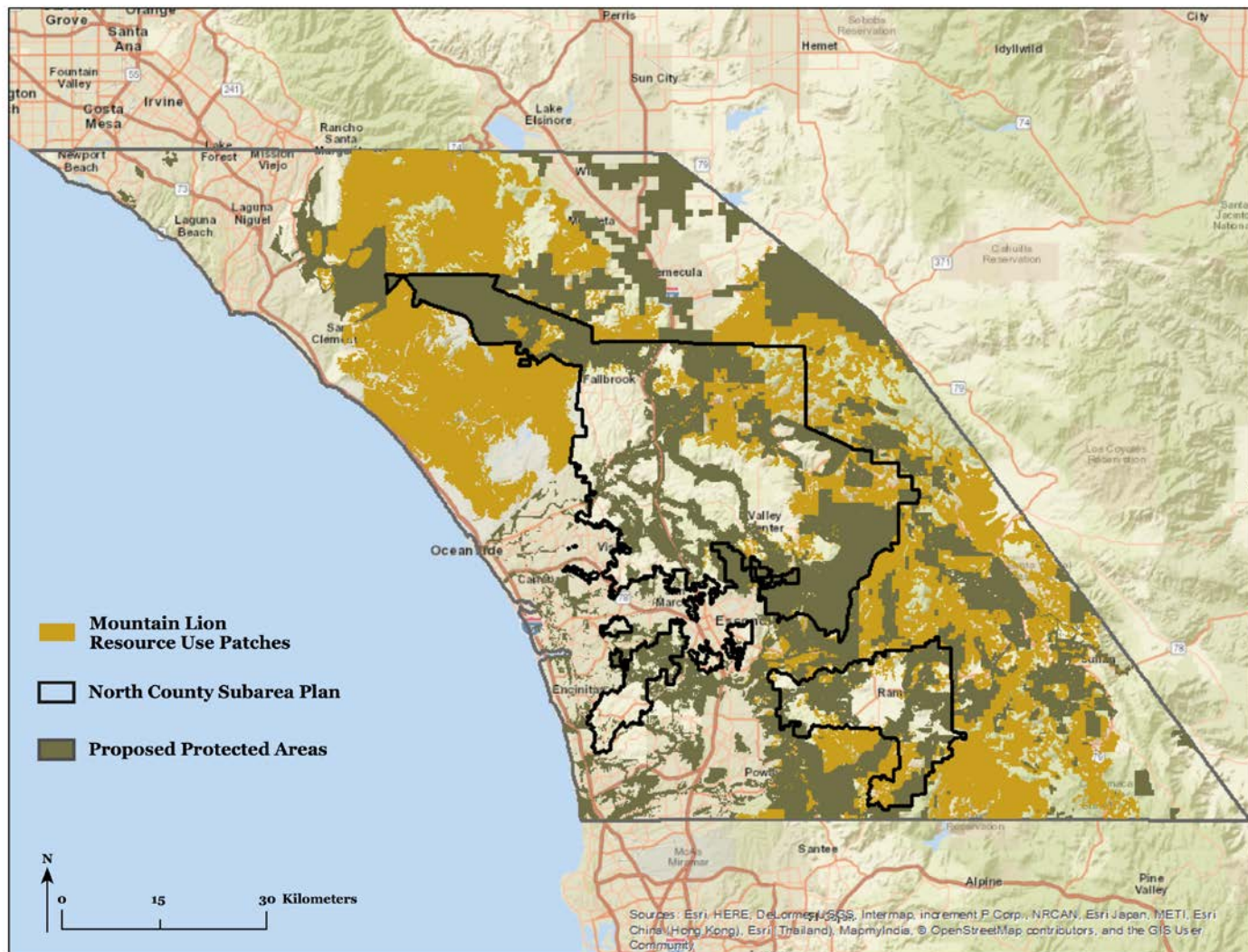**Figure 22 – Mountain lion resource use patches in relation to Proposed Protected (PAMA) lands**
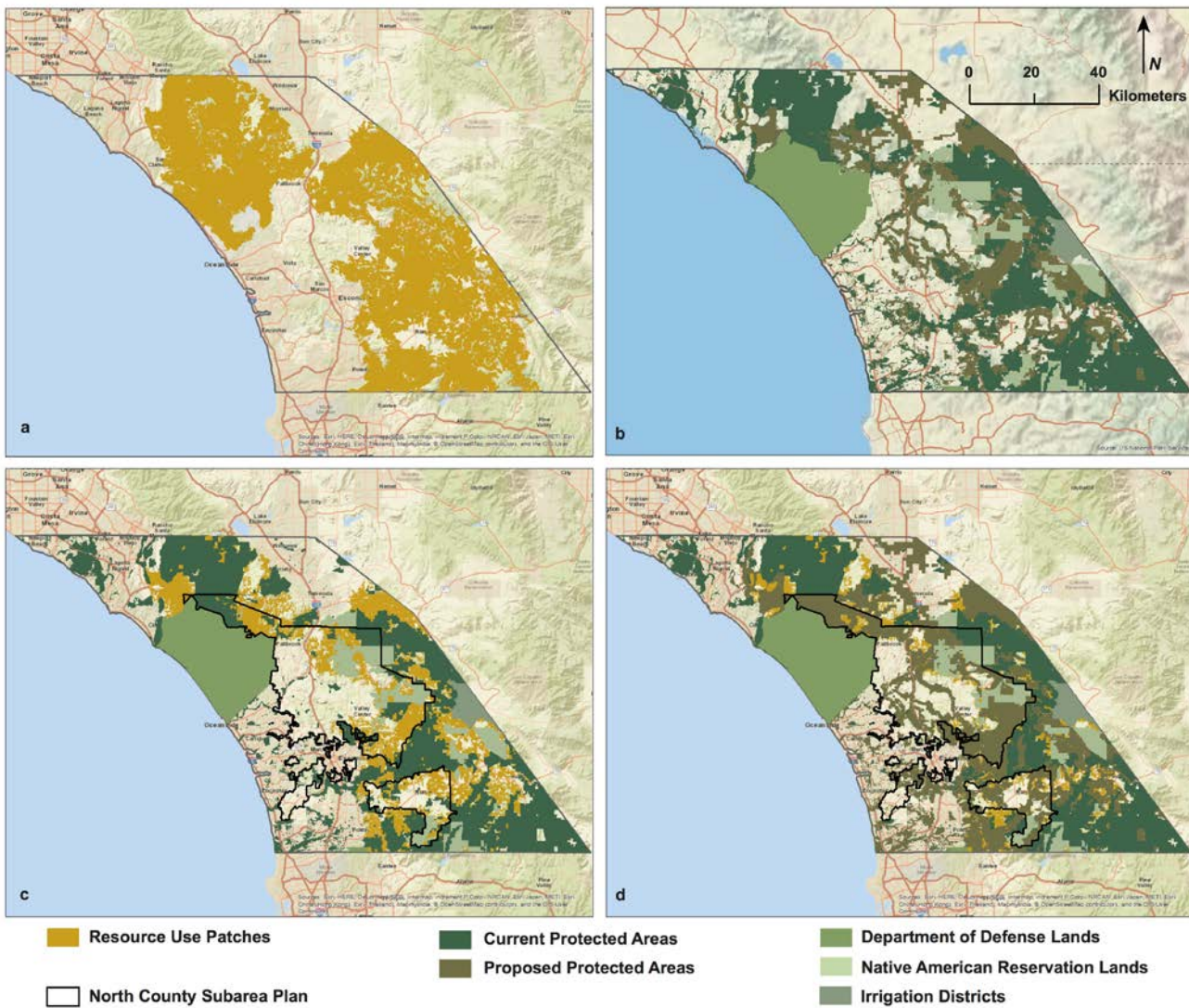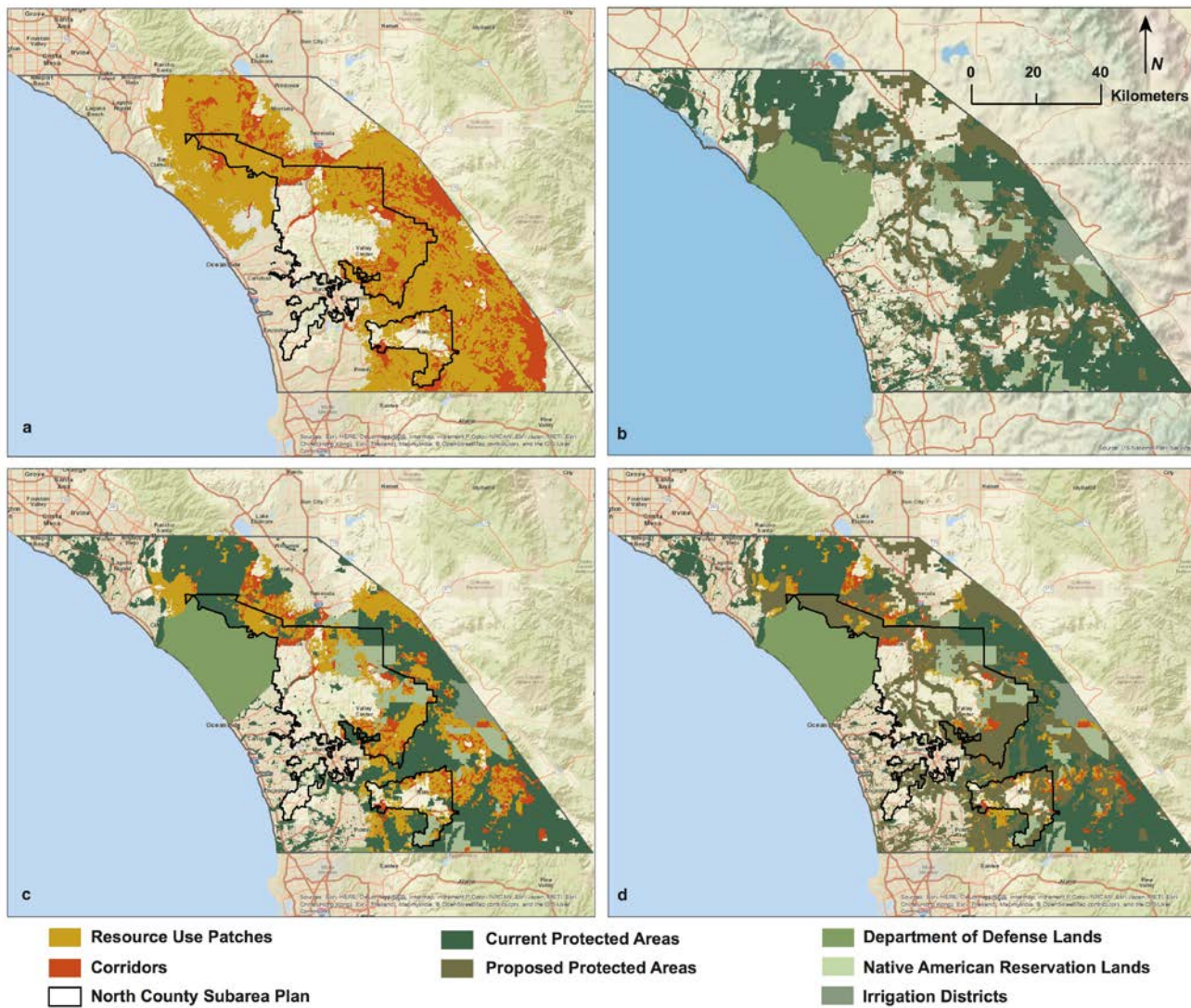
Figure 23. Mountain lion resource use patches in relation to currently protected or partially protected ((DOD, Native American Reservation, and I&WD) lands, and proposed protected (PAMA) lands.

We then looked at how well the current protected area network provided for mountain lion connectivity. We specifically examined the corridor areas that fell outside of the resource use patches. These corridor areas measure 777 km^2 and are shown along with the resource use patches (Figure 24a), the current protected and partially protected (DOD, Native American Reservation, and I&WD lands) network (Figure 24c), and with all current, partial and proposed protected areas (Figure 24d). Zoomed in views are provided in Figures 24 e,f,g (Appendix 4). The current protected area network overlaps with 47% of corridor areas, DOD lands capture an additional 2%, Native American Reservation lands an additional 9%, and I&WD lands capture an additional 1% of the corridors (Table 8). This leaves 41% of the corridors outside of RU patches on privately held lands (Table 8).

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Figure 24. Resource Use Patches, Corridors, and the current and proposed protected area network.

▮ Resource Use Patches	▮ Current Protected Areas	▮ Department of Defense Lands
▮ Corridors	▮ Proposed Protected Areas	▮ Native American Reservation Lands
▯ North County Subarea Plan		▮ Irrigation Districts

The proposed protected area network (PAMA lands) cover 29% of the corridor areas outside of the RU patches (Table 9, Figure 24d). Accomplishment of the target of 75% of PAMA lands being eventually conserved would result in capturing another 22% of modeled corridors outside of the RU patches , thus 69% of corridor lands outside of RU patches would be fully protected after completion of PAMA land acquisition targets (Table 9). An additional 12% of corridor lands outside of RU patches would be partially protected on DOD, Native American Reservation, and I&WD lands, thus 18% of modeled corridors outside of RU patches would be neither fully nor partially protected after full assemblage of the conservation network as currently planned (Table 9).

Looking at the entire mountain lion conservation network including resource use patches and corridors, it is clear the current protected area network is only moderately functional for mountain lion protection (Figure 24c, with zoomed in views in Figures 24e,f,g - Appendix 4). Incorporating the PAMA areas (Figure 24d) with 75% protection greatly improves protection for mountain lion resource use patches and corridors; however, only 62 –

68% (Table 9) of the RU patches and corridor lands outside the RU patches respectively are fully protected with completion of the planned conservation network. Though DOD and Native American Reservation lands clearly add habitat that can be utilized by mountain lions in relative safety, at least 12 – 18% (Table 9) of RU patches and corridor lands outside of RU patches respectively will still be in private ownership at the time of conservation network completion, thus subject to development. Mountain lions may use portions of private lands but are at higher risk when doing so. Given the increasing isolation of mountain lion populations in the region as documented in genetic analyses (Ernest et al. 2014; Gustafson et al. submitted), and low annual survival rates (Vickers et al. 2015), it is vitally important to permanently protect these resource use and corridor areas, as well as improve the identified road crossing locations.

RESULTS - I-15 Crossing Point Rankings from Experts Workshop

For I-15, the categorical and expert scoring indicated that retention and enhancement of function of the Temecula Creek Bridge, and construction of a new under or over pass south of the bridge, were both likely needed for long-term successful connectivity between the Santa Mountains and the eastern Peninsular Range. All the experts agreed that dependence on one site for assuring movement of all necessary species of wildlife adequate to accomplish gene exchange between populations in entire mountain ranges was unwise, and that failure to assure redundancy of connectivity risked continued genetic decline of mountain lions west of I-15.

Site 5 ranked highest in the expert scoring with six out of nine experts selecting it as the highest priority, and a wildlife bridge structure was considered by the experts to be the most functional for the widest array of wildlife and plant species, including mountain lions and deer, at that site (Appendix 5). Both the location and wildlife bridge concept are consistent with previous studies (Beier and Barrett 1993, Fisher and Crooks 2001, Luke et al. 2004). This site ranked second in the categorical landscape scoring, receiving fewer points in the land protection category because some parcels on the east side of the proposed bridge location are not yet protected. The exact location where a bridge structure would be placed in the stretch of the freeway encompassed by Site 5 would be dependent on engineering feasibility studies.

All experts ranked Site 1, Temecula Creek Bridge, as one of the top three crossing point locations; however, eight of the nine experts ranked this site as second or third priority, with only one expert ranking it as the highest priority location. Experts pointed to the fact that this site currently has the highest existing potential for wildlife movement, but has significant challenges to its proper function due to road noise and human presence. They felt that road noise and human disturbances could be sufficiently mitigated to increase this location's functionality for species such as mountain lions and deer.

Recommended improvements in the vicinity of the bridge included substantial reduction of sound and light pollution from traffic crossing the bridge, removal of lighting at the pump station on the west side of the bridge, prohibition of human presence under the bridge and in the creek bed at night

Prohibition of further human development and nighttime activity on the Temecula Creek golf course, and near the confluence of Temecula and Murrieta creeks and the Santa Margarita River on the west side of the bridge was strongly advised. Currently, substantial developments are proposed in both locations, and experts advised that if development goes forward it should be sufficiently modified to prevent interference with wildlife

movement. In addition, experts agreed that increased native vegetative cover should be established on the golf course to promote the use of the site by deer and other wildlife. Even if the proposed residential development moves forward, the experts felt that this crossing could still function for medium-sized carnivores, smaller wildlife and plants, but its function for mountain lions and mule deer would be further degraded.

Sites 4 and 3 were ranked next due to their general proximity to Site 5 and their similar characteristics in the landscape. Either of these could be alternative sites to site 5 for a new crossing structure, most likely an underpass. Should funding sources be identified, engineering studies would likely be used to determine exactly which type of structure and location would be most feasible.

Figure 31. I-15 potential crossing sites with rankings. Protected lands in blue. View is from Palomar mountains at bottom of figure looking NW (general expected direction of travel of mountain lions moving from the eastern Peninsular Range into the Santa Ana Mountains).

DISCUSSION

This study uniquely combined multiple methods to assess connectivity and habitat availability for mountain lions in the NCMSCP, and between it and other regional NCCP areas. Via our GPS data, and modeling of resource use patches and movement corridors, we have identified key areas within the region where land conservation and protection focus should be directed to increase the potential for mountain lion persistence on these landscapes long term.

Overall, our study found that only approximately one-third of modeled suitable habitat and corridors for mountain lions in the NCMSCP and nearby NCCP lands are currently on protected lands, and a somewhat lesser percentage is partially protected on DOD and Native American Reservation lands. Thus, in our opinion, efforts to conserve PAMA lands in the NCMSCP and adjacent north San Diego County and southern Riverside County areas should be a high priority, and be moved forward as expeditiously as possible. However, since our analysis suggests that even if 75% protection of currently designated PAMA lands is achieved, 12 – 18% of mountain lion habitat and corridors will still be left unprotected, we suggest that our models be used to re-examine PAMA designations and potentially expand conservation efforts further than currently planned. Our models should be used to help prioritize lands for conservation in order to help assure that conservation dollars intended for wildlife connectivity enhancement are most effectively utilized.

This study showed that I-15 and associated development, and I-10 and associated development and open desert (also not conducive to mountain lion movement), are serious barriers to both physical and genetic connectivity for mountain lions in the region. This genetic analysis confirmed that the mountain lion population west of I-15 continues to be seriously genetically restricted, and despite finding new evidence that five heretofore unknown additional animals besides M86 have crossed I-15 (2 more east to west and 3 more west to east) no evidence of reproduction by any of those animals was detected and two-thirds of them are deceased (including M86, along with nearly half of his offspring). These findings emphasize that though M86 may have had a positive influence on the genetics of this population, the barriers to new gene introduction remain high, and the risk of decline of the Santa Ana Mountains population due to low annual survival and genetic factors should dictate that efforts to improve connectivity across I-15 be a high priority. A Population Viability Analysis is underway for the mountain lion population west of I-15 that will take into account both demographic and genetic factors in order to assess the risk of extirpation of the Santa Ana Mountains population if connectivity is not improved.

Though overall genetic diversity was better in the mountain lion population east of I-15 than in the population west of the freeway, the lack of evidence of genetic connectivity with mountain lions to the north in the rest of California is significantly concerning. Lack of gene flow from the mountain lion population in the San Gabriel Mountains north of I-10 and other populations further north suggests that unless connectivity across I-10 is improved, long-term genetic diversity of mountain lions east of I-15 may be dependent on introduction of new genes from the east or south. Though whatever barrier effects are exerted by deserts to the east may not change much with time, movement of mountain lions to and from Mexico to the south may be more hindered by border security measures in the future. The team feels that further investigation of the nature of barriers and gene flow in all three directions should be the subject of further research.

In the case of the northern corridors across I-15 that our modeling identified at Temecula Creek and just to the

south, the Temecula Creek Bridge is the primary crossing structure that is currently available to accommodate safe crossings of the freeway by mountain lions and other wildlife. Though our study has not documented use of the Temecula Creek pathway by GPS-collared mountain lions that have approached the bridge from the west, the corridor model, FLCP model, and expert opinion (detailed below) all suggest that the Temecula Creek Bridge remains the most likely pathway for mountain lions to move safely across I-15, and the only crossing that gives direct access to large habitat areas on both sides. Given the levels of traffic on I-15 even during the night, and its width in the corridor area (8 – 10 lanes), it seems unlikely that successful crossings would have occurred at grade. One young female mountain lion attempted to cross I-15 in 2014 south of this bridge and was killed by a vehicle, and several other mountain lions have been killed on the freeway south of the bridge previous to that (Vickers et al. 2015). Thus, in our opinion the Temecula Creek Bridge crossing structure should be considered as the most viable crossing for the greatest number of species, including mountain lions, but it is in danger of serious degradation of function if proposed development on both sides of the bridge goes forward.

At this writing, the City of Temecula is considering proposals to allow substantial residential development in or near the corridor identified by our modeling, and on either side of the Temecula Creek Bridge.   Should the developments be built as proposed, especially the development proposed for the Temecula Creek Resort and golf course on the east side, it is our opinion that the function of this corridor and bridge for mountain lions will be degraded substantially.

Medium sized culverts south of the bridge are also available to wildlife, but they are minimally conducive to wildlife use due to their physical characteristic of ascending at steep angles east to west, with no visual continuity from end to end.

Viable locations for one or more new crossing structures just south of the bridge were identified via the corridor modeling and FLCP analysis reported here, and experts at the I-15 connectivity workshop ranked those locations south of the bridge highest for a new structure. However, construction of any new crossing structure will be very expensive, is likely far in the future at best, and no funding source has currently been identified. Thus we feel it is unwise to allow further degradation of the corridor in the vicinity of the Temecula Creek Bridge, and what connectivity remains there.

The San Luis Rey River is the second major corridor that the models identified as a likely movement pathway for mountain lions across I-15. The model suggests that this river pathway is less attractive to mountain lions as it moves westward, probably due to the close presence of development on both sides. If a mountain lion makes its way west in the riverbed to the Camp Pendleton area, it has to pass through various levels of development to get from the riverbed into the wild habitat to the north. This pathway was used by one dispersing male GPS-collared mountain lion (M56) to move west to east. That animal entered the riverbed near the ocean and followed it east until he deviated south near I-15, and crossed under the interstate at the Gopher Canyon Rd. interchange in the middle of the night. Further development along this corridor that would degrade its function should also be restricted in our view.

Our study results suggest that other highways in the NCMSCP and nearby regions are partial barriers to

mountain lion movement in areas where development abuts the highway. In other areas, these highways pose a risk of mortality for mountain lions and other wildlife, and potential for human injury in wildlife-vehicle collisions. We suggest that more focus needs to be placed on improving safety for wildlife and humans in areas we have identified as high-crossing areas by improving or adding wildlife crossing structures where necessary, and adding fencing to funnel animals to crossings and exclude them from the roadway. A fencing project undertaken on SR241 in Orange County by the Foothill Eastern Transportation Corridor Agency has substantially reduced wildlife roadkill and increased use of existing crossing structures by wildlife. This project could be a good model for future projects along sections where risk of wildlife-vehicle collisions are highest.

Mortality levels in the mountain lion populations in the region remain a substantial concern. Loss of animals, predominantly males, to depredation permits in San Diego County not only diminishes the total population but also reduces the number of animals that are the primary gene dispersers in this species. Losses of mountain lions to depredation permits in this region are almost totally preventable when good livestock husbandry practices are employed. In a survey our mountain lion project team conducted in 2003, over half of San Diego County residents who owned small livestock did not adequately protect them from predators (Vickers 2007). We feel that this is an area where collaborative research and education efforts that are already underway, involving our research team, UC Extension, UC Davis Veterinary School Extension, the Mountain Lion Foundation, 4-H clubs, and others, can have a positive impact on this phenomenon and reduce unnecessary losses of both mountain lions critical to gene dispersal and domestic animals.

In summary, the NCMSCP contains substantial habitat for mountain lions and retains connectivity with other NCCPs in the region, though connectivity for mountain lions and potentially other species is seriously constrained both by the I-15 and I-10 freeways, and also to a degree by state and county highways and development in many areas. Some highway sections present higher risks for wildlife-vehicle collisions, and these should be evaluated for improvement. As development proceeds on private lands in the region, loss of habitat and connectivity will steadily erode the ability for mountain lion populations in the region to remain stable unless conservation actions are taken that substantially expand land protection, reduce mountain lion mortality rates, and increase connectivity above current levels.

Lastly, loss of connectivity for mountain lions and other wildlife species in southern California is a regional problem that has been created over time by hundreds of local development and highway decisions. Despite very large investments in time and money in conservation throughout the region, and despite the dependence of mountain lions on good regional connectivity, decisions about critical actions that can diminish or enhance connectivity (such as across I-15) are still being made primarily at the local jurisdiction (single city or county) level. We recommend further actions be taken to strengthen regional coordination, oversight, and if possible cost sharing, to effect a broader approach to conservation for animals such as mountain lions that have to cross many human-created boundaries to survive. We also urge the state and federal wildlife agencies, and county and city officials, to strongly consider regional impacts to mountain lion connectivity and populations when making local regulatory, development, and conservation decisions.

FURTHER RESEARCH AND OUTREACH NEEDS

1. Resource use, movement, and corridor modeling in the portions of Riverside County north and south of I-10. Define locations where improvements may be made to connectivity across that freeway and other potential barriers in that region.

2. Genetic research into connectivity of San Diego populations of mountain lions with populations to the south and east.

3. Genetic, physical, and demographic monitoring of the very low genetic diversity Santa Ana mountain lion population to detect signs of genetic defects (heart defects, sperm problems leading to infertility, etc.) and population decline such as were seen with Florida Panthers.

4. Further research into ways of reducing predation of small livestock by mountain lions.

5. Further research into the specific factors that appear to be currently inhibiting gene flow between mountain lions to the north and mountain lions in San Diego County.

6. Increased education in methods of predation reduction for those classes of domestic animal owners most likely to have animals at risk from mountain lions.

7. Development and testing of curricula relating to proper livestock husbandry for predator protection for 4-H and FFA participants.

8. Further defining of specific measures (crossing structures and fencing) that are indicated to maintain what connectivity remains across major highways in the region.

9. Investigation of cost-efficient, non-invasive methods to track mountain lion movement and genetic connectivity and diversity long-term.

10. Projection of the expected effects of future fire regimes and climate change on the vegetation types and patterns that support mountain lion persistence.

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