Estimating Mountain Lion Habitat Connectivity to Guide Wildlife Conservation at The Nature Conservancy's Jack and Laura Dangermond Preserve

Authored by:

Meghan Fletcher | Alyssa Kibbe | Grace Kumaishi | Anna Talken | Nikole Vannest

Faculty Advisor: Kelly Caylor

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Signature Page

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Meghan Fletcher	Alyssa Kibbe	Grace Kumaishi

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Anna Talken	Nikole Vannest

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The Group Project is required of all students in the Master of Environmental Science and Management (MESM) Program. The project is a year-long activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Group Project Final Report is authored by MESM students and has been reviewed and approved by:

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Abstract

The California landscape has become increasingly fragmented as urban development, infrastructure, and agriculture has expanded across the state. Maintaining connectivity between areas with prime wildlife habitat is important for the viability of many long-ranging species, such as the mountain lion (*Puma concolor*). Mountain lion populations are highly susceptible to the negative impacts associated with habitat fragmentation, including reduced access to hunting grounds, increased human-lion conflict, and decreased genetic diversity. This study explores the habitat connectivity between the Jack and Laura Dangermond Preserve (JLDP), a 24,460 acre protected property owned by The Nature Conservancy (TNC), and neighboring protected areas to identify potential pathways of movement for mountain lions along the Central and Southern California coast. In this project, we: 1) determine regional connectivity and least cost paths between core habitats by modeling suitable mountain lion habitat and areas with high resistance to movement in regions adjacent to JLDP, 2) estimate mountain lion habitat use and movement on JLDP by performing a site-level suitability and corridor analysis and 3) create a science communication film focused on highlighting our research, the role that JLDP plays in conservation, and the importance of habitat connectivity. The results of our project show that JLDP contains suitable habitat for mountain lions and may play a positive role in coastal connectivity. When considering the connectivity between JLDP and other regional protected areas, our analyses indicate that urbanized coastal zones, inland areas near Santa Maria, and the eastern edge of the Los Padres National Forest act as barriers to mountain lion movement and contain pinch points, potentially impeding and channelizing mountain lion movement. These results can guide TNC in developing wildlife conservation and management strategies for mountain lions on JLDP and in the surrounding region. Recommended future conservation efforts for TNC include restoring and protecting habitat where migratory routes are highly channelized to allow for more dispersed movement, as well as creating wildlife corridors to increase connectivity between areas of high quality habitat.

Significance

As urban development and land use change continues to expand across California, habitat fragmentation due to roads, fences, and other infrastructure can be potential barriers to wildlife movement. Ensuring connectivity between essential habitats is crucial for many long-ranging species, such as the mountain lion (*Puma concolor)*. Protecting wildlife corridors helps to maintain healthy mountain lion populations and promote genetic diversity between populations. Mountain lions are often referred to as an umbrella species, a species that is chosen for conservation efforts because of the indirect benefits to other wildlife, due to their large range and habitat use. Protecting mountain lion habitat and prioritizing corridor conservation may also yield significant conservation benefits for other species.

The Nature Conservancy's (TNC) acquisition of the Jack and Laura Dangermond Preserve (JLDP), a 24,460 acre protected area surrounding Point Conception in Santa Barbara County, presents a rare opportunity to preserve a landscape that may be important for wildlife connectivity in the region. The results from this project will feed directly into TNC's management planning for large carnivore conservation.

Results of this project include a thorough literature review, a mountain lion habitat suitability model, a preserve-level connectivity model and a regional analysis of mountain lion habitat connectivity. These methods, models and results are created to be utilized by TNC as they continue to expand their conservation management and planning. Additionally, a goal of this project is to educate and engage the local communities, specifically local middle and high school students, through a film focused on habitat connectivity and the conservation work at JLDP. It is our intention that our work will provide useful models, conservation recommendations, and science communication material for TNC.

Background

Wildlife Habitat Connectivity

Establishing corridors to promote habitat connectivity for wildlife has become increasingly important as natural landscapes continue to be fragmented as a result of human activity. Human activity, such as urbanization, agriculture, and the development of infrastructure can pose imminent threats to wildlife (Bennett 1999, Beier 1993, Wynn-Grant et al. 2018, McClure 2017). Maintaining connectivity between landscapes has been shown to increase the genetic diversity and reproductive capacity of wildlife populations, specifically those that have large ranges (Gustafson et al. 2017, Dellinger et al. 2020, Singleton & McRae 2013). Many species of wildlife must have access to different habitats throughout their life cycle for purposes such as breeding, feeding, and overwintering (Steckler & Brickner-Wood 2019). Connection between important habitats increases the overall fitness of a population by providing essential gene flow as individuals can more easily move across the landscape (Gustafson et al. 2018). When populations are isolated, the risk of extinction increases (Benson et al. 2016).

Mountain lions must often traverse human-inhabited and developed areas in pursuit of their prey. As urban sprawl encroaches into wild areas, the habitats and resources mountain lions rely upon continue to be impacted. A recent study found that genetic diversity varies greatly between the nine distinct populations of mountain lions *(Puma concolor)* across California, which can largely be explained by habitat fragmentation (Gustafson et al. 2018). For example, the population of mountain lions located within the Sierra Nevadas is the most genetically diverse population in the state - likely due to the lack of human presence in that region. Conversely, the southern and coastal mountain lion populations appear to be genetic sinks, places that typically contain lower quality habitat and require the immigration of individuals from other areas to maintain a population (Gustafson et al. 2018, Draheim et al. 2016). In these regions, lion populations suffer from fragmented gene flow, likely due to the large amount of urban growth that has occurred over the last several decades (Gustafson et al. 2018). One study found that the mountain lion population in the Santa Ana Mountain Range would become extinct if it was confined to its 1990s habitat size of 75 square-kilometers, yet connectivity between core habitats in the area have allowed this population to survive

(Beier 1993). With populations in the southern and coastal regions far more susceptible to inbreeding, it is imperative to increase habitat connectivity across the state, which will ultimately improve the viability of California mountain lions.

Previous studies suggest that pristine, unaltered habitats are preferred corridors for wildlife, and highly mobile species may avoid areas influenced by anthropogenic development or land use change (Wilmers et al. 2013, Hilty & Merenlender 2004, Smallwood 1994, Machtans et al. 1996, Beier 1995). A 1995 study found that juvenile mountain lions frequently use corridors, including waterways under highway bridges, streams, ridgelines, and dirt trails, and prefer traveling on routes that were free from artificial light (Beier 1995). In order to determine priority areas to create wildlife corridors for long-ranged species such as the mountain lion, it is imperative to determine areas of habitat that are most suitable for the species.

Mountain lions in California

Mountain lions are one of the largest carnivores in California and play a fundamental role within the ecosystems they inhabit (Ernest et al. 2003, Barry et al. 2019). Since 1990, they have been listed as a “specially protected species” within California which has made hunting this species illegal unless a depredation permit is issued by the California Department of Fish and Wildlife (CDFW)(USDA Forest Service 2020, Dellinger et al. 2019). In 1920, there were approximately 600 mountain lions in California, and as predation pressure has subsided, populations have now stabilized between an estimated 2,000 and 6,000 individuals (USDA Forest Service 2020, CDFW 2020).

Today, mountain lions have territories that span most of the western United States, including throughout California (CDFW 2020, Pierce & Bleich 2003, Dellinger et al. 2019). An adult male lion can hold a territory of up to roughly 750 square-kilometers, while females tend to have smaller territories typically about 100 square-kilometers in coastal landscapes (Nicholson et al. 2014, Grigione et al. 2002). A young male mountain lion may disperse up to 480 square-kilometers from their birth place in order to establish their own territory (Pierce & Bleich 2003).

Habitat and Prey Preferences

Mountain lions' large range includes a vast array of habitats, from the desert to the coast, and from sea-level to elevations greater than 3,000 meters across California's mountainous terrain (USDA Forest Service 2020, Nicholson et al. 2014, Pierce & Bleich 2003, Grigione et. al 2002). A study by Dellinger et al. (2019) found that roughly 40% of the state likely contains mountain lion habitat. The landscapes and resources that attract mountain lions are found to be higher elevations, greater numbers of deer, areas farther away from open landscapes, and areas that are closer to forests, shrub cover and secondary roads (Dellinger et al. 2019). Mountain lion movement in California is highly driven by the search for their main source of prey, mule deer, along with other prey species (Ahlborn 1988, Laundré 2010). A year-long dietary study of seven mountain lions in Northern California's Mendocino forest found that 99% of their prey biomass consisted of deer (Allen et al. 2015).

Human-lion interactions

Although mountain lions are elusive, solitary animals, with few human interactions, a number of factors related to habitat use and prey have caused these interactions to become more frequent. Most importantly, urbanization across California has encroached on and fragmented critical mountain lion habitat (Thorne et al. 2006, Gustafson et al. 2018). In addition, mountain lions are increasingly drawn towards urban areas in pursuit of mule deer, which frequently move into these areas to evade predation (Fergunson et al. 2005). Finally, smaller animals such as racoons, rabbits and mice are also commonly seen in urban areas and are preyed up by mountain lions on occasion (Alldredge et al. 2019). A study by Wilmers et al. (2003), found that mountain lions required a larger buffer from developed areas when engaging in reproductive behavior, including denning and communication, as compared to non-reproductive behavior such as feeding (Wilmers et al. 2013). Large, protected natural areas away from urban development may play a key role in providing refuge and resources for these large carnivores.

Study Area

Figure 1. Map of the Jack and Laura Dangermond Preserve, managed by The Nature Conservancy. Highlighted in green with a locator map in the upper right corner depicting its location in California (ESRI, 2017).

Surrounding Point Conception in Santa Barbara County, the Jack and Laura Dangermond Preserve (JLDP) is a 24,460 acre property that consists of oak woodlands, annual grasslands, chaparral and 8.5 miles of pristine coastline (Figure 1)(Butterfield et al.

2019). JLDP lies on native Chumash lands, home to important cultural sites such as villages, cemeteries and rock art sites that date to over 9,500 years ago. In 1542, the first Spanish explorers arrived on this section of the coast, ultimately displacing most of the native tribes that had inhabited this region for thousands of years. Mexican ranchos purchased territory in this region to establish cattle ranches along the coast from 1816 to the late 1870s (Butterfield et al. 2019). Cojo Ranch and Jalama Ranch, two historical cattle ranches, still exist on the landscape today. In 2017, JLDP was donated to The Nature Conservancy and remains a biodiversity stronghold as one of the last wild, protected areas along the Southern California Coast. Adjacent properties include Vandenberg Space Force Base on the western edge of JLDP and Hollister Ranch, over 14,000 acres of privately owned land that runs along the eastern boundary and connects JLDP to the Los Padres National Forest and Gaviota State Park (Butterfield et al. 2019).

JLDP is located at a biogeographic boundary where the southern and northern ranges of many species overlap. The Mediterranean climate, pristine beaches, and topographic diversity make this area a unique refuge for many plants and animals. Just offshore from this remote stretch of coast lies the Point Conception State Marine Reserve, a 22.52 square mile marine protected area that safeguards important ocean habitats, from reefs and kelp forests to harbor seal haul outs and rocky pinnacles (CDFW 2015).

Located near other developed coastal areas, JLDP may be a safe haven for many species with large ranges that are negatively impacted by habitat fragmentation caused by infrastructure, roads, and agriculture. The primarily uninhabited and wild landscape offers quality habitat and resources for wildlife. As habitat fragmentation impedes animal movement and threatens the survival of many species, protecting and managing wildlife corridors is essential for developing effective conservation management plans within and surrounding JLDP.

Habitat Connectivity Modeling

Habitat connectivity models have been widely used to inform conservation management across the globe. Using data to inform on the landscape such as elevation, vegetation type and plant or animal presence points allows researchers to generate both single and multi-species connectivity models. Habitat connectivity models can help researchers understand how different landscapes may or may not be impacting ecological flow, which can largely influence where conservation efforts should be focused (McRae & Singleton 2013). Using mountain lions to model connectivity is a fundamental step in determining how they may access different core habitats using the least cost path, or the path with the lowest resistance to movement.

Suitability Model: Maxent

Maxent, or maximum entropy, is a tool used to model habitat suitability. Suitable habitat is influenced by multiple environmental factors such as vegetation class, elevation, land use type, and distance to roads. Suitability models such as Maxent, allow researchers and stakeholders to identify potential habitat use by a species across a landscape (Dellinger 2019). Maxent utilizes observation data, specifically presence data only, and environmental variables important to species distribution to estimate habitat suitability (Almpanidou et al. 2014). Habitat suitability models can help scientists and organizations like The Nature Conservancy generate conservation management strategies that most appropriately serve any species of interest.

Circuit Theory Models: Circuitscape

Circuitscape utilizes circuit theory to model connectivity among habitats of variable suitability (McRae et al. 2013). Electrical circuit theory in Circuitscape treats landscapes as conductive surfaces and uses the Markovian Random Walks principle to map the likelihood that an individual will cross through a cell depending on the levels of resistance, voltage and current (McRae et al. 2008). These currents, or pathways, moving through the landscape are used to identify bottlenecks, denoted as pinch points, in connectivity corridors. Pinch points, or areas of bottlenecking, describe where individuals are either moving through patches or narrow natural areas, and the loss of this space could be detrimental to wildlife (McRae et al. 2016).

Algorithm results from Circuitscape can be visualized using ArcGIS using the Linkage Mapper Toolkit (Steckler & Brickner-Wood 2019). By combining essential ‘nodes’ or core habitats for the focus species with the permeability of the landscape in the form of a resistance raster, researchers can create a model to illustrate the possible connective network between habitat cores. For example, a 2017 study on habitat connectivity for mountain lions in the American Southwest used circuit theory models to identify pinch points and bottlenecks that will be most affected by future development in that region (McClure et al. 2017).

Circuit Theory Models: Omniscape

Omniscape expands on the circuit theory established in Circuitscape to calculate the current between each pixel on a landscape, rather than between cores (McRae et al. 2016). Omniscape, similar to Circuitscape, uses a resistance raster describing the permeability of a landscape. The resistance layer is used to calculate the source strength layer, determining the amount of current available to move through each pixel. Omniscape relates high source strength with presence point data causing there to be higher source strength when there are more presence points in one area (Landau et al. 2021).

Additionally, Omniscape produces three current maps: cumulative current flow, flow potential, and normalized current flow. Cumulative flow reveals the total current that each pixel contains. Flow potential demonstrates the predicted current in a resistance-free scenario. Finally, normalized current is the ratio of the cumulative flow and the potential flow, which can be used to assess connectivity between each pixel on a landscape (Landau et al. 2021).

Science Communication on JLDP

Science communication is becoming a top priority for many organizations, research agencies and academic institutions. Being able to effectively communicate scientific findings with the public is key for spreading awareness and inspiring change. One of TNC's major goals for JLDP is to generate a science communication curriculum that highlights the importance of JLDP for conservation, acting both as a protected area for wildlife as well as an educational space for local communities. Specifically, JLDP is uniquely situated to serve local communities by providing a natural laboratory for local students to explore natural ecosystems and conduct research. By creating an educational curriculum for JLDP, TNC will be able to broadcast its conservation achievements and inspire young conservationists in the process. Because JLDP is situated between San Luis Obispo County and Santa Barbara County, TNC is focused on engaging middle and high school students from both counties through both classroom and field-based curricula.

Science Communication through Film

Over time, film has continued to gain popularity as a means of science communication. Films that can captivate diverse audiences, bridge knowledge gaps, share perspectives, and inspire action can be incredibly effective in engaging the public (Nisbet & Scheufele 2009). Visual representations of nature through both media and art have become critical avenues for human exploration into the natural world and have also broadened public understanding of various species, landscapes and biodiversity as a whole. Utilizing these forms of science communication allows film-makers and researchers alike to bring remote species and places that are rarely captured on camera to the public in a safe and non-intrusive format.

Film and other sources of media also tend to drive emotional appreciation and engagement from diverse audiences which generates increased environmental awareness. Enabling the public to formulate these linkages to nature through media has vast impacts on policy support, human attitudes and narratives, and environmental engagement that may ultimately benefit entire conservation movements (Silk et al. 2017). To communicate the findings and importance of the research on mountain lion habitat connectivity that is covered in this report, we produced a short film for TNC to share with local communities and stakeholders.

Mountain Lions in the Media

As one of California's largest carnivores, mountain lions have attracted high levels of public attention. A study focused on understanding mountain lion perception amongst social media users found that most people had positive attitudes towards these large predators (Greenspan et al. 2021). However, not everyone positively views these large carnivores; it has been shown that people with children as well as consumptive recreators tend to have a more negative perception of the species (Greenspan et al. 2021). Science communication about the importance of these large carnivores for ecosystems is critical for influencing public perceptions and advancing conservation efforts. One study revealed that there is currently a great need for developing more public education in regards to the positive impacts mountain lions have on ecosystems and human-wellbeing in order to offset the antipathetic media attention mountain lions receive after a negative human-lion interaction occurs (Wood et al. 2021).

By producing a short film focused on mountain lion habitat connectivity within and around JLDP, we aim to develop a meaningful film that can be included within JLDP's educational curriculum as well as serve as a useful communication tool for TNC to share with other important stakeholders. By highlighting the overall importance of mountain lions and the need to protect the species through improved habitat connectivity, our goal is for this film to generate an appreciation and understanding of these large carnivores. Through this film, we also hope to inspire discovery and highlight the importance of preserving natural landscapes, such as JLDP, and maintaining habitat connectivity for mountain lions and other wildlife species.

Objectives

1. Model mountain lion distribution in regions adjacent to the Jack and Laura Dangermond Preserve (JLDP) to determine regional connectivity and least cost paths (LCPs) between potential core habitats.
2. Estimate mountain lion use on JLDP by performing a site-level suitability and corridors analysis.
3. Create a science communication film focused on highlighting our research, the role that JLDP plays in conservation, and the importance of habitat connectivity.

Methods

Regional Connectivity Model

Preprocessing

Mountain lion presence data was collected from two sources, iNaturalist and camera trap images captured on JLDP. All presence data (158) from iNaturalist are research-grade, meaning verified by a scientific professional. Presence points were exported to ArcGIS and clipped to our ROI. Camera trap images were processed by Pig Patrol (Bren GP 2021) to identify the species captured in each image. Mountain lion observations were added to ArcGIS Pro in the EPSG 4269 (NAD83) coordinate system. For Maxent use, the presence data was exported as a CSV containing species name, latitude and longitude for each observation.

Environmental variables were collected from a number of open-source databases including those owned by NASA, CalFire, California Department of Fish and Wildlife (CDFW), ESRI, and Conservation Science Partners. Each layer was clipped to our ROI and projected to EPSG 4269 (NAD83). Topography layers dated back to the year 2000, but all other environmental layers were created between 2015 and 2021. The following environmental layers were collected to incorporate into the habitat suitability model: open areas (labeled barren/other), elevation, landform, multi-scale topographic position index (MTPI), primary roads, shrub, slope, streams, topographic diversity (TD), trees (combined hardwood and conifers), and urban areas (Appendix 1). Code to download elevation, landform, mTPI, TD, and slope using Google Earth Engine is housed here.

We calculated the Euclidean distance for certain environmental variables as performed in a published study by Dellinger et al. (2019). Additional studies found that rugged, scrub/shrub dominated areas constituted high quality habitat for mountain lions, further validating our decision to use these vegetation layers (McClure et al. 2017). Euclidean distance processing was completed for the roads, shrub, urban areas, trees, barren/open areas, and streams layers. After being clipped to the ROI in ArcGIS Pro, we reclassified each layer to replace values to NoData for all layers except the layer of interest. Using the ArcGIS Euclidean distance tool, we calculated the distance to the max extent of the study area in order to avoid data gaps (Figure 2).

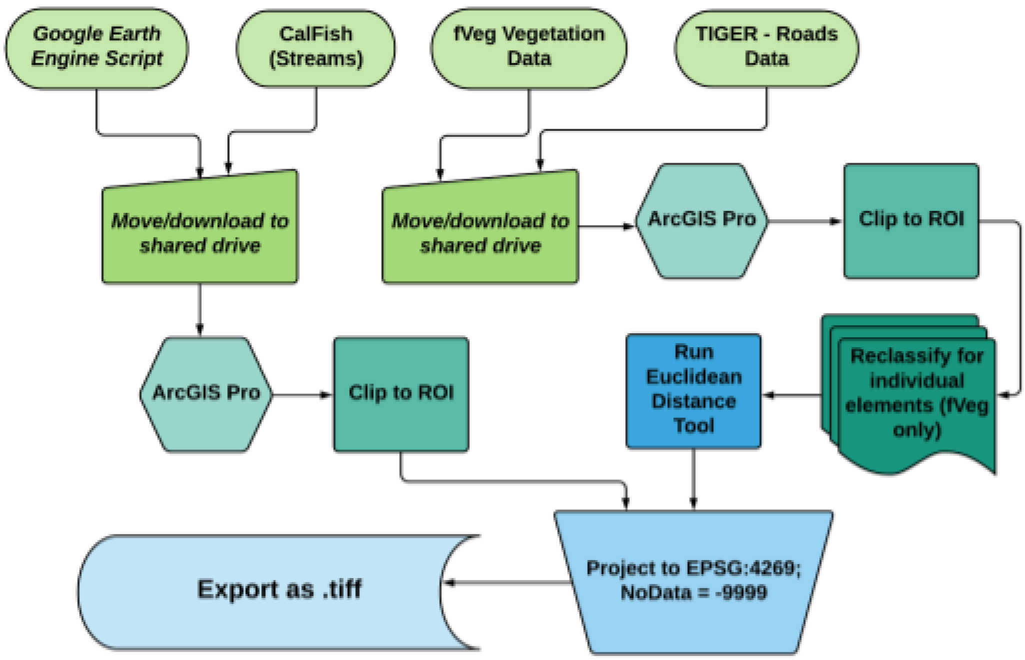


Figure 2. Workflow for Data Acquisition and Euclidean Distance Pre-processing. Data acquired from Google Earth Engine and CalFish were downloaded, clipped to the ROI, projected into the proper coordinate reference system (CRS) in ArcGIS Pro before exported as .tiff files for future use. Data acquired from fVeg and TIGER were clipped to the ROI, reclassified to keep individual elements (fVeg data only) and calculated euclidean distance using the Euclidean Distance tool in ArcGIS Pro. All datasets were projected to the correct crs and no data values were set to -9999 before being exported as .tiff files.

Suitability Modeling

Maxent

We created the mountain lion habitat suitability model using the open-source tool Maxent (Version 3.3.3k, October 2011). Initially we included: barren/open areas, elevation, landform, multi-scale topographic position index (MTPI), distance to roads, distance to shrub, slope, distance to streams, topographic diversity (TD), distance to trees, and distance to urban areas. Of our environmental factors, all were continuous variables except for the categorical landform layer. Many model iterations were performed to determine the key environmental variables to be included in the final analysis (Appendix 2).

Each environmental factor was weighed in Maxent to determine which condition had the greatest influence on the model outputs. To do so, we selected the “do jackknife to measure variable importance” setting from the main window to allow Maxent to automatically evaluate each variable together and individually. We also selected “create response curves” to visualize the relationship among variables. Further visual analysis was completed using ArcGIS Pro. Rasterization of the model outputs allowed us to further compare the model’s outcome.

Resistance Layer

We placed the Maxent output (.asc) into ArcGIS Pro, used ‘Define Projection’ tool to define the projection to NAD83 - EPSG: 4269, and then used the ‘Raster Calculator’ tool to convert to resistance. We converted the suitability layer to a resistance raster using a negative exponential equation as suggested by Keeley et al. (2016) as it was found to best translate suitability to resistance for large mammals with wide ranges. We used the this equation to convert the habitat suitability to mountain lion resistance using the Raster Calculator in ArcGIS: $resistance \ = \ e^{-suitability}$. We used the ‘Reclassify’ tool to convert the resistance layer from continuous to categorical with five resistance classes for ease of Omniscape use before exporting as a TIFF (.tif).

Connectivity Modeling

Circuitscape

We selected three core habitats based on TNC’s research interests which includes the Jack & Laura Dangermond Preserve. We determined the other two cores using a CalFire land ownership dataset, choosing Big Sur and Los Padres National Forest which are categorized as USDA Forest Service land. For the southern core (Los Padres), the largest continuous region was selected to reduce the amount of small unconnected polygons surrounding the main region (Appendix 3).

Inputs for Circuitscape included the calculated resistance layer and the outline of the three core habitats. Using the ArcGIS toolkits Linkage Mapper, Barrier Mapper, and Pinchpoint Mapper, we calculated the least cost path, barriers to connectivity and pinch point locations between the three core habitats (Appendix 4). We repeated the suitability and connectivity modeling steps using a suitability analysis produced by Dellinger et al., 2019 to compare our results using community science and camera trap observations to collared movement data.

JLDP Model

Suitability Layers

Five biotic and abiotic layers that were pulled from TNC's geodatabase for JLDP were used to determine habitat suitability within the boundaries of JLDP: streams, vegetation, paved roads, fences and Digital Elevation Model (DEM)(Table 1). Streams, roads, and fences were rasterized and the Euclidean distance was calculated to the extent of JLDP. Vegetation is a categorical variable consisting of herb, shrub, and tree-dominated areas, as well as non-vegetated, and agricultural areas. Mountain lion observations taken via camera traps range from 2014-2022, with multiple observations per camera location. Repeated observations were jittered by 50m to avoid over-correlation to a micro-landscape.

Table 1. Data Collection Table. Data used to create suitability and resistance layers used in deriving JLDP landscape conductance for mountain lions.

Dataset	Source	Date collected	Short description
Elevation (DEM)	Aeroptic	2018	Digital Elevation Model via LiDAR
Vegetation	CalFire - FRAP	2012-2014	Categorical vegetation layers, refined into 5 categories.
Fences	ProActive Engineering	2012	Existing fences around JLDP
Roads	CMR	2012	All roads around JLDP; we utilized paved roads only
Streams	USGS & A&M	2001	All streams around JLDP

Maxent

In order to run the JLDP-specific model, a new suitability layer was created using Maxent. Similarly to the methods for the regional connectivity model, multiple iterations of Maxent outputs were created using various combinations of the five habitat layers described above. Jackknife sampling was used to determine the importance of individual environmental factors, and response curves were used to further understand the relationships between these factors. Steps to create the resistance raster followed those described in the regional connectivity model.

Omniscape

Our study utilized Julia version 1.7 using the package "Omniscape". The model input was the derived resistance layer from Maxent suitability analysis. Before running the model, we set the configuration options including the radius, block size, source from resistance, r cutoff and reclassify resistance. Most of these settings were determined by the example provided by the Julia homepage (Landau et al. 2021, McRae et al. 2016), reducing the block size to 3 and radius to 50. Since we reclassified the resistance layer within ArcGIS Pro, we used the `"source_from_resistance" => "false"` statement to opt-out of reclassifying the resistance layer. Map calculations included a cumulative current map, flow potential, and normalized current flow. Cumulative current map shows the movement of current throughout the landscape. Flow potential depicts the connectivity if resistance was one for the entire landscape. Normalized current flow combines both of these by dividing the flow potential by the cumulative current map.

Results

Regional Analysis

Habitat Suitability

We used statistical criteria: Area Under the Curve (AUC), Jackknife test, response curves and individual variable contribution to determine the most suitable outcome as well as visually determining ecoplausibility by comparing to previous studies. The final model that was chosen based on the methods described above included the following environmental variables: distance to shrub, topographic diversity, barren landscape, elevation, distance to streams, slope, landform, distance to urban areas, and distance to roads. Ultimately, distance to trees and mTPI were dropped as the former was highly correlated with distance to shrubs (<0.7) and the latter contained missing data that reduced the AUC statistic (0.005). Our AUC statistic is 0.865 (Appendix 5). Distance to shrubs contributed the most (percent contribution) to the model (26.4)(Appendix 6) and most of the suitable area can be found near this vegetative feature (Figure 4). However, in the jackknife test of variable importance, TD was found to have the most useful information by itself, and elevation to have the most information that is not present in other variables (Appendix 7).

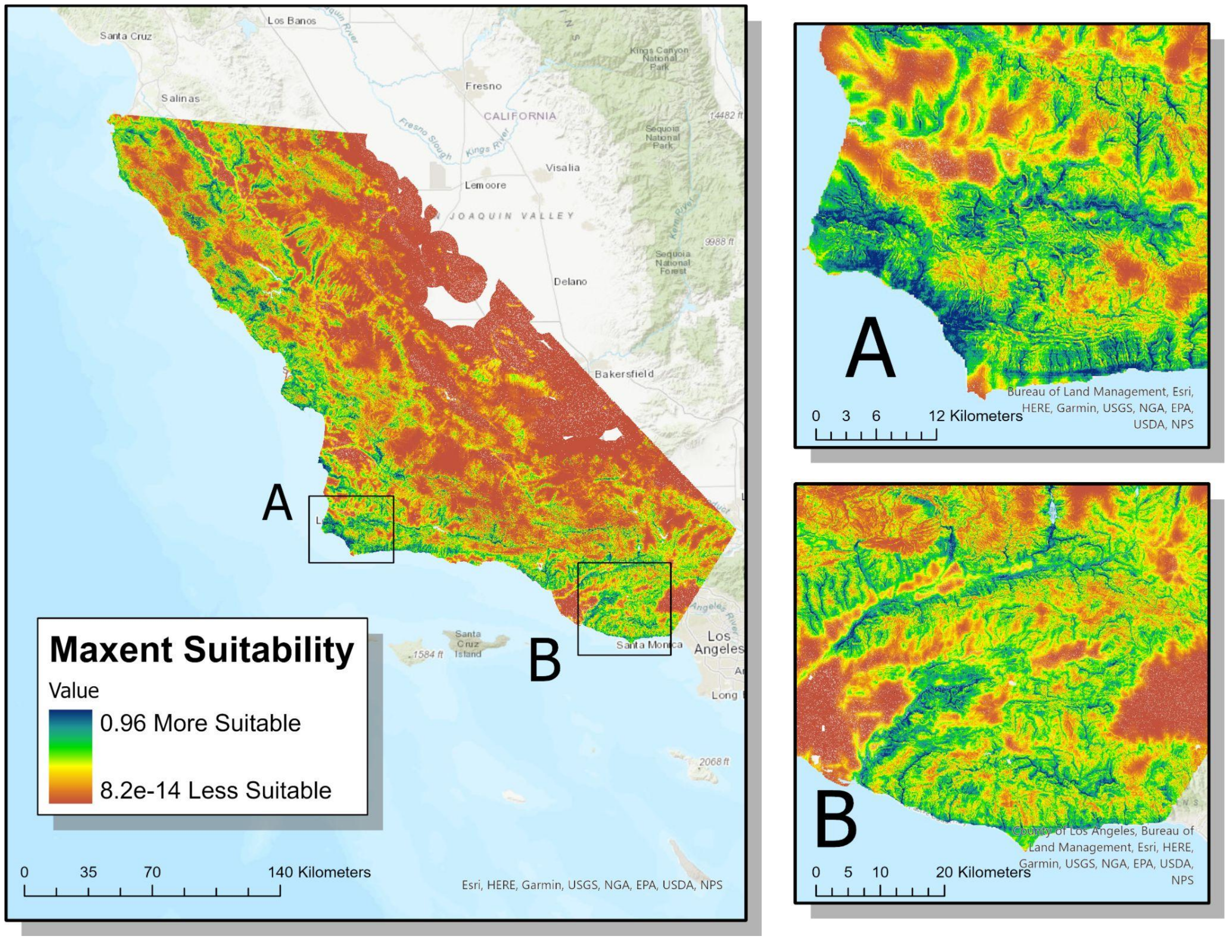


Figure 4. Habitat Suitability Model. Maxent suitability model after removing distance to trees and mTPI environmental variables. Cool colors represent areas of highly suitable habitat while warm colored areas depict low suitability. Map A in the upper right corner depicts Point Conception and Map B depicts areas near Malibu and Santa Monica.

Resistance

Previous studies have performed suitability analysis with collared lion tracking data (Dellinger et al. 2019), and we transformed this study's suitability output using the negative exponential function in order to compare its resistance to that of our study. Our resistance layer ranged from approximately 0.3 to 1, and the collared resistance from approximately 0.6 to 1. The difference between the two layers was taken using the raster calculator in ArcGIS Pro. The result ranged from -0.319 to 0.59 with the majority of discrepancies within geomorphologic features as described by the Topographic Diversity input layer (Figure 5). Many of the differences are also congregated near JLDP, most likely due to the many presence points our study utilized in this area, and more detailed information about the habitat of JLDP.

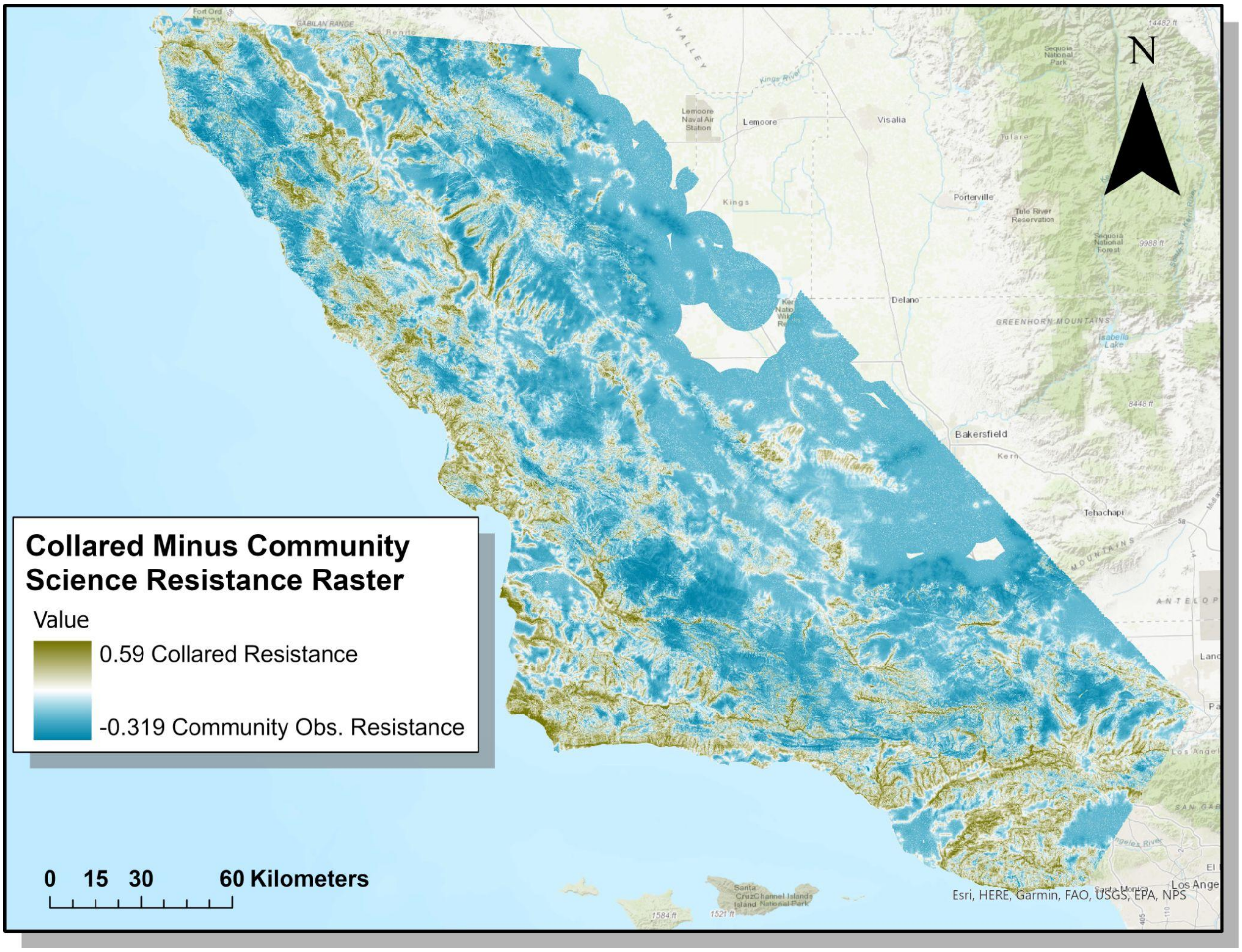


Figure 5. Collared Minus Community Science Resistance Raster. Converted suitability rasters via negative exponential function were differenced to compare where the largest discrepancies are in resistance. High values describe higher resistance in the collared raster, lower values as higher resistance in our community science driven raster and zero values describing similarity between the two rasters.

Circuitscape

Least Cost Path (LCP): Performing the Build Network and Map Linkages tool in ArcMap analyzed the areas on our resistance layer where it would be the least effort to move from one core to the next. Movement from JLDP to Los Padres, the LCP is not the euclidean distance but rather takes a route closer to the coastline (Figure 6), with a cost-weighted to euclidean distance ratio of 0.66 (Appendix 8).

The LCPs between the community science data and the collared data show many similarities (Figure 6). There are small discrepancies close to the northern core and between JLDP and the southern core. The differences in these paths may be due to the influence of topographic diversity on the Maxent suitability map that is not present in the collared data suitability study. We also saw some differences between the two resistance layers, with the collared raster consisting of more median resistance values than the Maxent raster. The difference between these two layers may be due to the limitations of using camera traps and community data, which is clustered more in the Urban Wildlife Interface (UWI) than potentially true, ideal habitat.

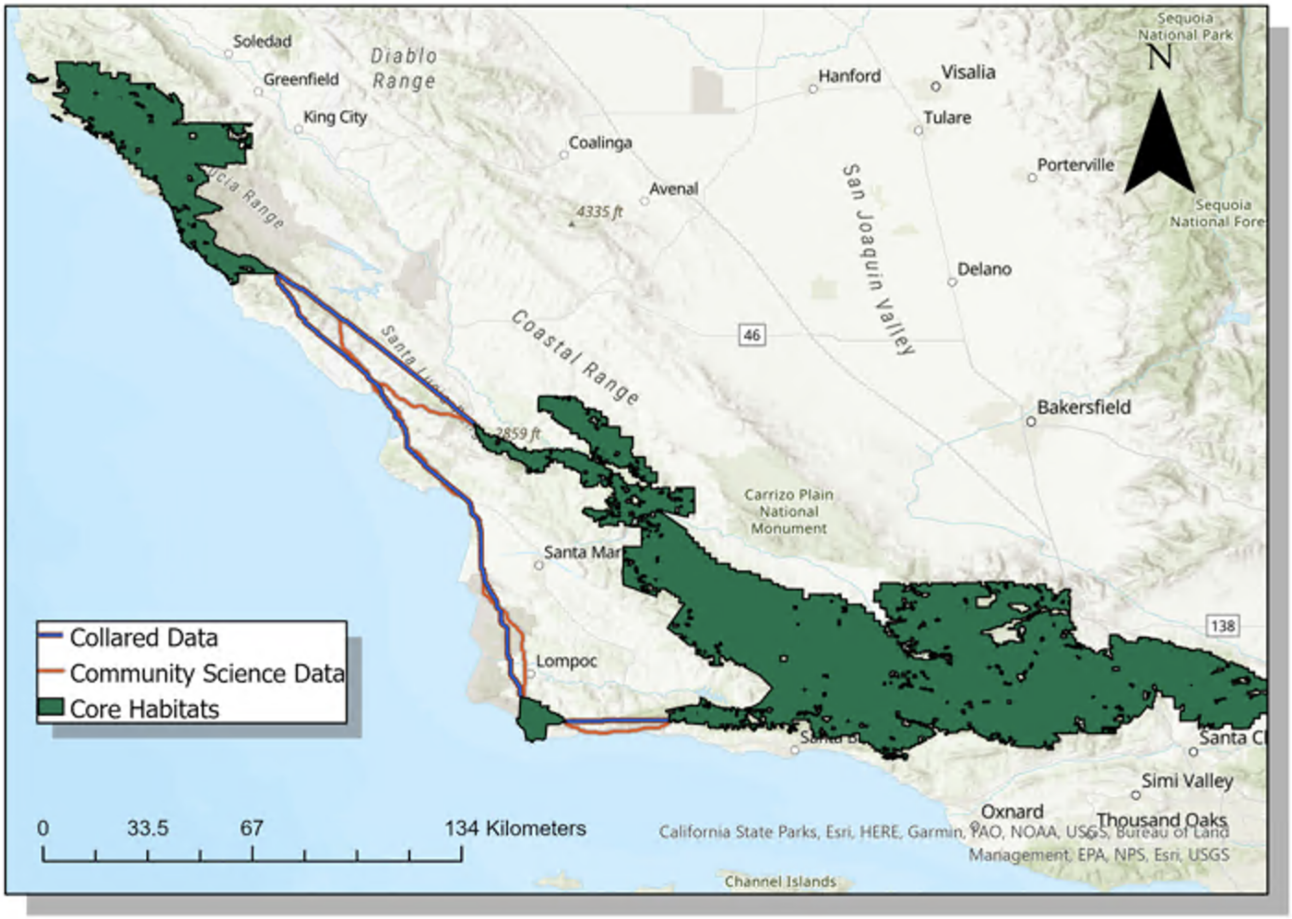


Figure 6. Least Cost Paths. The LCP measures the least energy costly path for a mountain lion to travel between the core habitats. The blue path was calculated using the resistance layer from the collared lion dataset while the red path comes from the community science dataset.

<u>Barriers and Pinch Points</u>: Pinch points, narrowing or bottleneck sections of the corridor, are clustered around urban areas to the north (Morro Bay and Pismo) and the private land of Hollister Ranch (Figure 7). Barrier mapper calculates potential barriers to connectivity. Barriers are found over urban areas such as Santa Maria and Lompoc, as well as over certain high elevation peaks (Appendix 9).

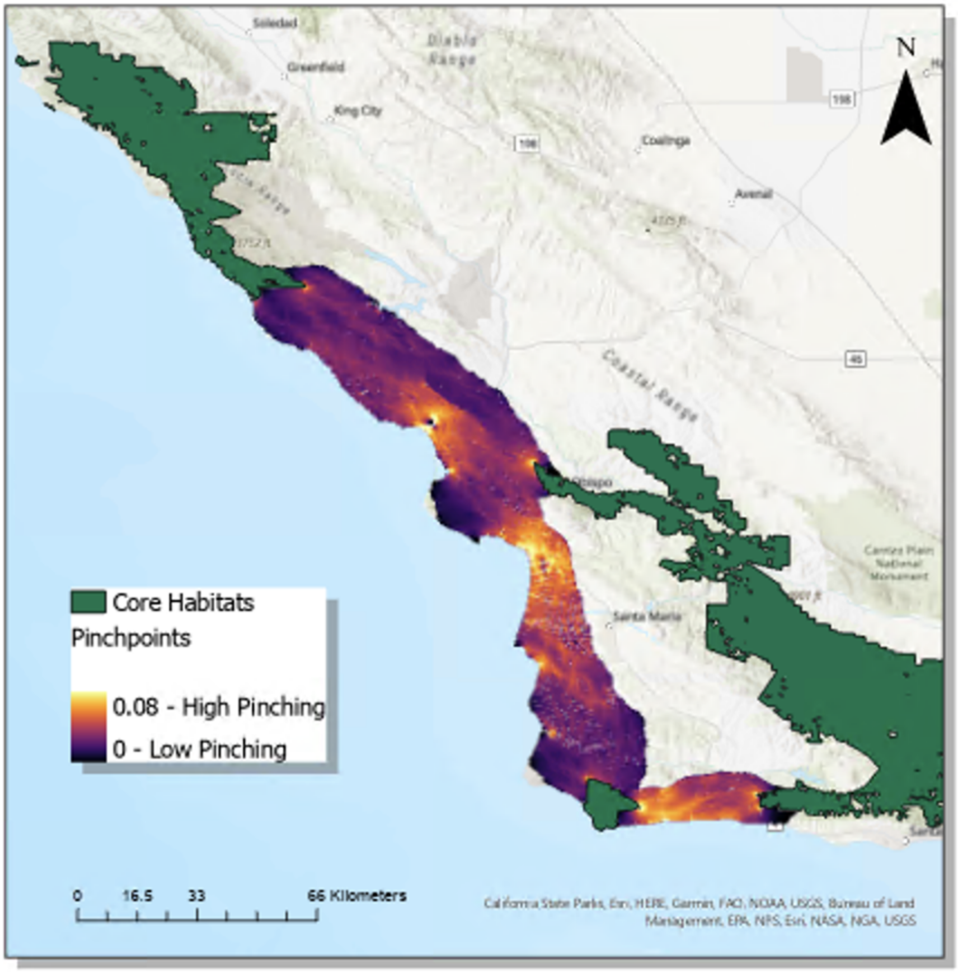


Figure 7. Pinchpoint Map. Pinch points are areas where the LCP for community observations is narrowed or bottlenecked, causing a smaller connecting route. Areas with higher pinching are areas of concern that may require stricter protection to ensure the corridor is not lost due to development.

Omniscape

We utilized the resistance layer from the Circuitscape regional analysis to look at corridors and landscape conductivity across the Central and Southern California coast. Coastal areas near Santa Lucia Range, Morro Bay, Burton Mesa, Jalama, and between Carpinteria and Ventura were highlighted as being areas of highly channelized conductance, surrounded by more disperse areas (Figure 8). Inland areas near Santa Maria and the eastern edge of the Los Padres National Forest were also more channelized than the surrounding area. Urban areas, Pismo Beach, Isla Vista, Santa Barbara and Ventura were found to be lower in conductance and considered areas of impeded movement.

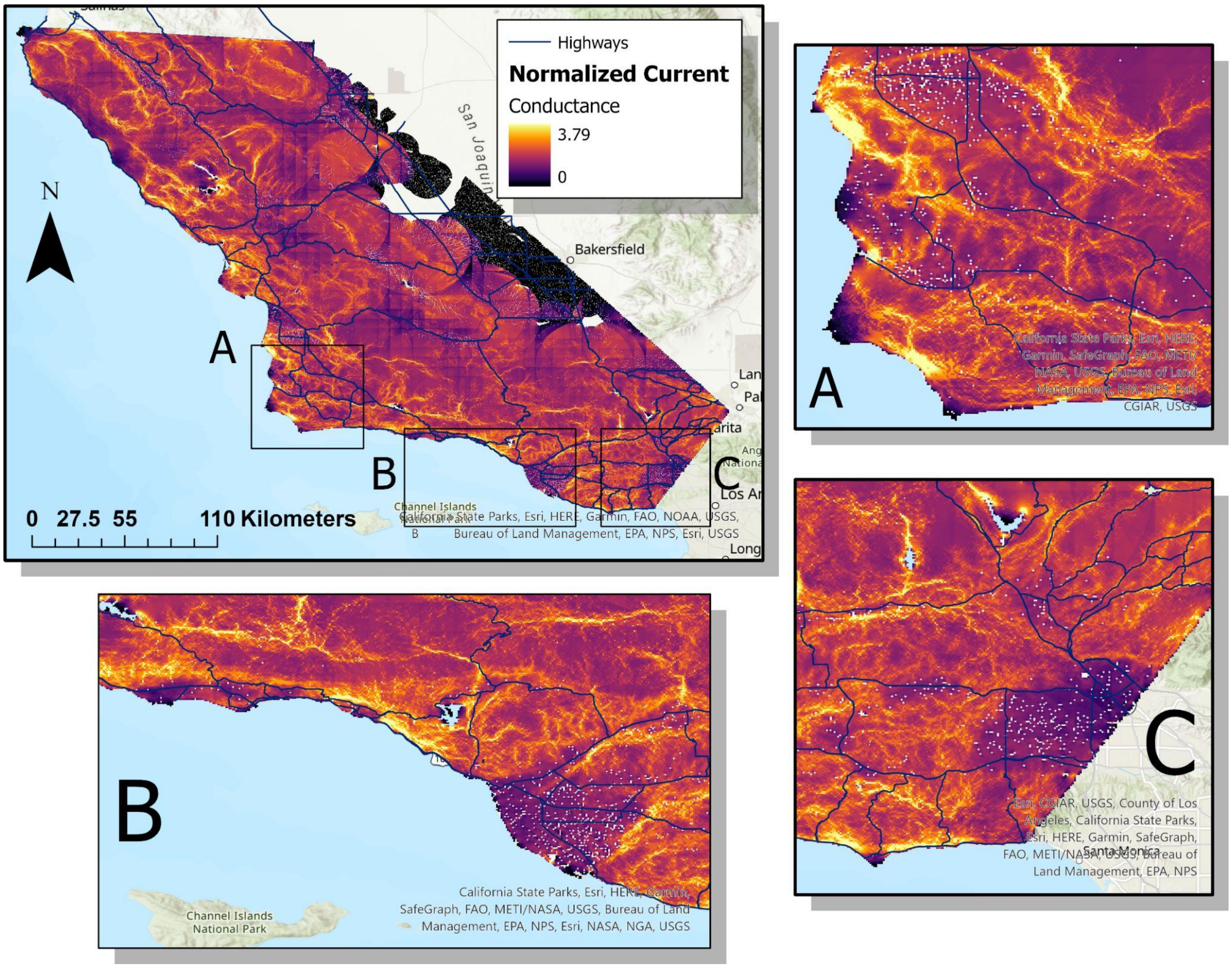


Figure 8. Regional Omniscape Map. Omniscape results depicting regional connectivity for areas between Big Sur and north of Santa Monica. Conductance is depicted as high being lighter and low being darker areas. Major freeways are depicted as black lines within the region of interest.

JLDP Analysis

Habitat Suitability

Suitability layers were run in Maxent with initial output showing DEM to not be a significant contributor to the overall model so it was dropped in later iterations. The categorical vegetation layer contributed most when considering percent contribution and permutation importance (82.1, 33.9)(Appendix 10), with the non-vegetated areas being the most significant indicator. Euclidean distance to streams was secondarily important (6.7, 39.9)(Appendix 11) with its response curve falling more dramatically as the distance to streams increases.

Omniscape

Omniscape output from a continuous resistance raster depicts the entire JLDP to have medium to high conductance with areas closer to streams, non-vegetated and shrub-dominated areas with a slightly greater channelized flow (Figure 9). Darker areas around the edges depict barriers to movement and are caused by edge effects near the boundary of the study area. The southern section of JLDP near Government's Point and Point Conception were not considered by the model as they were cut off by some of the input layers. We would expect the point to act as a barrier due to its close proximity to a cliff, and because in this area ice plant is the primary vegetation type, which is not suitable habitat.

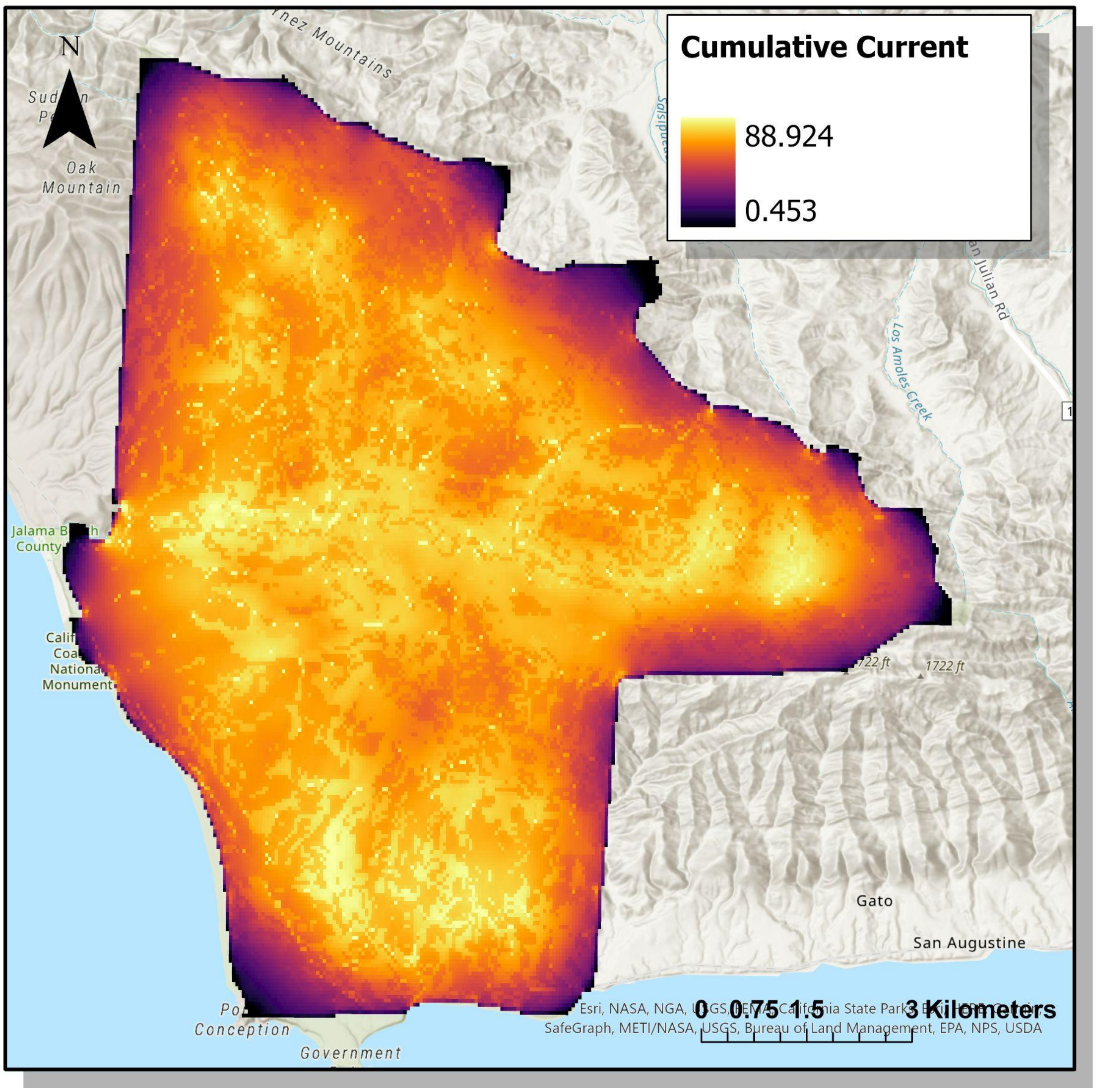


Figure 9. Cumulative Conductance Map. Output depicting areas of high to low conductivity (light to dark) using Omniscape modeling tool across JLDP.

Limitations

JLDP as a Node

The core areas used in this analysis, Big Sur and Los Padres forest, were 126,800 and 663,150 hectares respectively. JLDP is roughly 9,900 hectares and significantly smaller than the two others cores. In addition, JLDP is a smaller node than those used in previous mountain lion habitat connectivity studies. One study identifying least cost pathways for mountain lions along California's Central Coast stated that the researchers used a minimum core size of 40,460 ha (Thorne et al. 2006). However, other research suggests that even when accounting for immigration via corridors, an area between 60,000ha and 160,000ha is needed to support a mountain lion population without significant risk of extinction in the next 100 years (Beier 1993).

Connectivity and Barriers

Within JLDP, barriers (distance to roads and fences) were used as suitability indicators for the habitat suitability model but were not good predictors of suitable habitat and may actually favor distances closer to fences due to the locations of some of the camera traps (Figure 10). Non-vegetated landscapes, such as beaches, were more favorable yet much more patchy across JLDP. Higher suitability in these areas may be a result of the locations of mountain lion sightings. Areas of reduced suitability, or barriers to movement around Point Conception and northern edges of JLDP may be due to higher resistance from a higher distance from streams, a lack of observations, and edge effects caused by the boundary of the preserve. Further research and improved presence data from collaring mountain lions would improve the accuracy of these models.

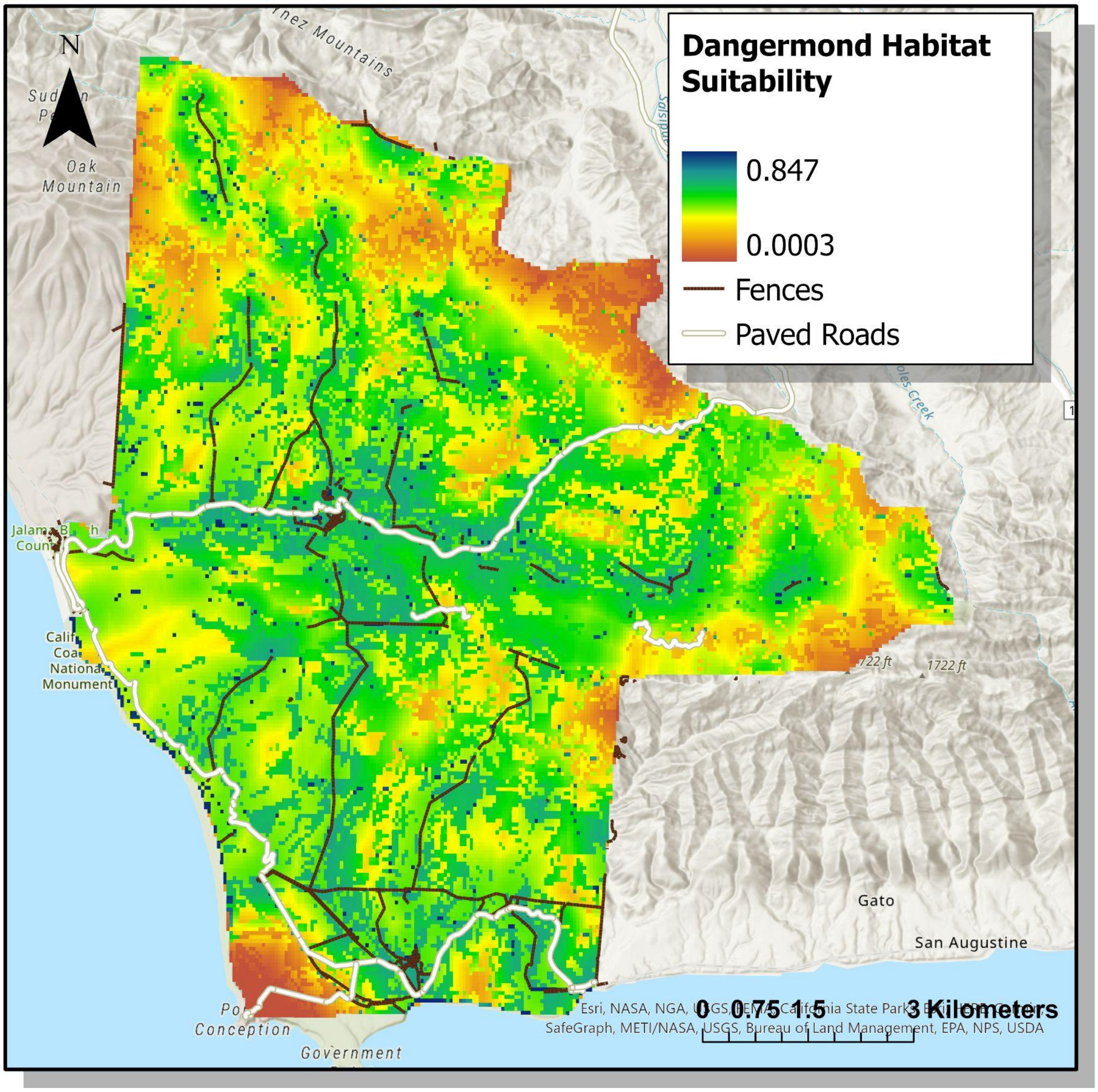


Figure 10. JLDP Habitat Suitability and Barriers Map. Mountain lion suitability analysis by Maxent suitability model on JLDP. Fences and roads are depicted by black and white lines. Suitability is depicted from blue (high) to red (low).

Camera Trap and Community Science Data

Relying on camera trap images and community science observations to map mountain lion suitability is inherently biased, and does not necessarily create a true image of suitability but rather a map of where cameras and people have opportunistically spotted mountain lions (Kolowski & Forrester 2017). Many of the observations used in our regional analysis are close to wildland urban interfaces (WUI), where residential areas encroach on wild ecosystems. Additionally, many of the camera traps utilized in our preserve-level study were placed along the coastline, similarly biasing results because there was not an equal distribution of camera traps amongst different vegetation types on JLDP. In order to generate more accurate presence point data, future data collection should ensure cameras are distributed across a breadth of different landscape types from the mountains to the coast to develop a more comprehensive understanding of where mountain lions may be when collared data is not available.

Conclusions

JLDP’s Role in Preserving Connectivity

Based on our regional analysis, it is evident that urban areas are a substantial barrier to movement and cause bottleneck effects along the various least cost paths (Figure 8). The largest barriers described in our report are near highly fragmented areas due to urban development, especially in the Lompoc, Santa Maria, Pismo, San Luis Obispo and Morro Bay areas. For example, highways such as Highway 101 pose a significant threat to mountain lions trying to cross from one landscape to another. According to the Cougar Conservancy, about one hundred mountain lions are killed on the roadways every year. Mountain lions are known to have large ranging territories and these territories can sometimes be intersected by major roads and highways. Additionally, mountain lions are obligate carnivores, so they must follow their prey to sustain themselves, forcing them to occasionally traverse across these developed landscapes.

Preserves such as JLDP are especially important within these highly fragmented landscapes such as the Central and Southern California Coast because they provide protected nodes of connectivity for wildlife to utilize as they move throughout the landscape. With the development and conservation of these nodes, we would expect to see less wildlife death across various roadways. Additionally, with more wilderness areas like JLDP, populations of mountain lions may more easily interact which would enhance the genetic diversity of some of the more fragmented populations such as those in the Santa Ana Mountain Range.

Both our Circuitscape and Omniscape analyses provide TNC with the preliminary data necessary to interpret which areas within and around JLDP will be the most beneficial to improve habitat connectivity. More specifically, coastal access on JLDP seems to be an area of favorable movement for mountain lions and other large mammals as depicted in Figure 4. Protecting wildlife corridors, especially those near coastal natural areas, will increase the opportunities for wildlife to access habitats that are important for feeding and breeding throughout the region. By placing monitoring equipment such as camera traps along the potential corridors highlighted in our analysis, TNC will be able to understand how frequently mountain lions are utilizing these pathways and which areas may need further protection.

Although we noted that JLDP is smaller than areas that are typically used as a node in mountain lion connectivity analyses, the results still have meaningful implications for current and future conservation efforts along the California coast. As shown in Figure 6, if mountain lions are traversing from the northern Los Padres core (Big Sur) to the southern Los Padres core, then the LCP will be the shortest distance between those two regions. However, as we see when incorporating JLDP as a node, two new LCPs are generated that run along the coast between Big Sur and the JLDP and along the coast between JLDP and the western fork of the Los Padres forest near Santa Barbara. Mountain lions have been well documented on the JLDP, including within close proximity of the ocean, suggesting that mountain lions may be utilizing the ocean for food resources. Therefore, the pathways that mountain lions use to migrate from the Los Padres forest to the coast, indicated by the LCPs that our model generated, are useful for understanding how these large carnivores access coastal zones.

Coastal Carnivore Significance

Currently, little research has been done with regard to how terrestrial carnivores utilize coastal areas and beaches. There have been no studies conducted on how mountain lions might be using JLDP's coastal areas for resource and habitat use, yet preliminary evidence from camera trap images offer insight that coastal areas are accessed by carnivores, including mountain lions. From camera trap images taken on JLDP, it is clear that terrestrial carnivores are using the coastline for feeding. Cameras placed along the coast captured multiple images of coyotes carrying cormorants (Figure 10), a type of seabird that utilizes the coastline to flock and nest. Camera trap images also revealed multiple mountain lions and bobcats heading towards the shoreline. It is possible that these carnivores may be using the coastline to find more prey.

Due to urban development along much of Claifornia's coastline, many coastal regions are dominated by human infrastructure and remain relatively inaccessible to many large carnivores. However, JLDP is uniquely situated to provide wildlife in the region with safe access to a portion of California's undeveloped coastline. With this protected stretch of coastal access, it is possible that carnivores like coyotes, bobcats, mountain lions and even black bears may be utilizing the coast more in this region. Future research is needed to determine how and why large carnivores are using coastal regions.

Figure 10. Camera Trap Photo. A solo coyote walks up from the nearby shoreline within the JLDP's boundaries carrying a cormorant. Cormorants are a native seabird species that aggregate along California's coastline.

Using Community Science Observations

Collared GPS data is extremely valuable for tracking species movement but can be challenging to acquire. In addition, collared studies take many years to get approved and require additional waiting periods and permits to collect enough data. This is especially true for high-priority species like mountain lions that toe the line between a listed threatened and endangered species in California, making existing collared data more difficult to acquire. Our study describes, while there are limitations, community science data can produce valid results for mountain lion connectivity modeling in the Central and Southern California coastal region. When collared data is unavailable, community observations through iNaturalist or similar sources could be an adequate substitute until collared data is made available.

Future Research

Collaring mountain lions on JLDP would give researchers a more precise understanding of how this protected landscape is being utilized by this species. There are still many unanswered questions surrounding not only mountain lions but other terrestrial carnivores that reside near coastlines. For example, how often do these animals access the coast and what coastal resources do they utilize? Do sea fauna provide a significant source of food for these mountain lions and other wildlife? How much does the coast aid in connectivity between patches? Continued monitoring of the coast using camera traps, collared animals and future models with more accurate and updated data could help in answering these questions.

Ensuring habitat connectivity in the face of continued development and climate change is crucial in species conservation (Singleton & Rae 2013). Researchers have developed “Representative Concentration Pathways” (RCPs) that aim to predict various scenarios related to future greenhouse gas emissions up to the year 2100 (Hausfather 2018). In addition, land use projections such as the CLUMondo model by the IVM Institute for Environmental Studies and NASA’s Land Use and Land Cover Classification (LULCC) can be utilized as an environmental layer in the Maxent model or overlaid with future species distribution models incorporating climate projections alone (van Vliet & Verburg 2017). Creating these projected suitability and connectivity models may prove useful in influencing TNC’s long-term goals and conservation efforts around JLDP, giving a clearer picture of changing corridors and suitable habitat for mountain lions in the future.

Conservation Recommendations

From both our habitat suitability and habitat connectivity analyses, we have generated a comprehensive list of future conservation management recommendations that TNC could use to further advance conservation efforts within and around JLDP. We would like to emphasize a caveat to our suggestions as they are based on results derived from camera trap images, not movement data. A more robust study using collard mountain lion data should be performed for more focused conservation recommendations.

1. **Future regional and preserve-level conservation efforts should focus on existing corridors and channelized areas.** Local urbanization in this region can cause channeling, or narrowing of the wildlife corridors, which are already highly susceptible to destruction or removal from continued development. Highly channelized regions west of Lompoc such as Jalama Beach and Vandenburg Space Force Base (Appendix 12) should be top conservation priorities for maintaining crucial wildlife corridors, avoiding further habitat fragmentation, and improving habitat connectivity for mountain lions as well as other wildlife that might be utilizing JLDP.

2. **Future restoration efforts should focus on the highlighted barriers, including the construction of wildlife corridors such as overpasses and underpasses.** Based on the least cost paths projected in Figure 6, it seems likely from both our results and collared results produced by CDFW that coastal areas are critical corridors for mountain lion connectivity in the region. Establishing wildlife corridors, such as highway overpasses, should be focused where the LCP crosses Highway 101 north of Gaviota State Park. Focusing mitigation efforts on these areas will reduce the challenges faced by mountain lions as they approach barriers when moving between viable habitats.

3. **Develop additional science communication materials focused on the importance of mountain lions and habitat connectivity in the region**. Generating public appreciation and understanding for both mountain lions and JLDP can greatly improve conservation research and policy support. In addition to our short film highlighting the importance of habitat connectivity for mountain lions, we recommend creating a diversity of educational materials such as a series of short films on this topic that could be used as part of TNC's educational curriculum on the Preserve for local middle and high school students.

Project Communication Deliverables

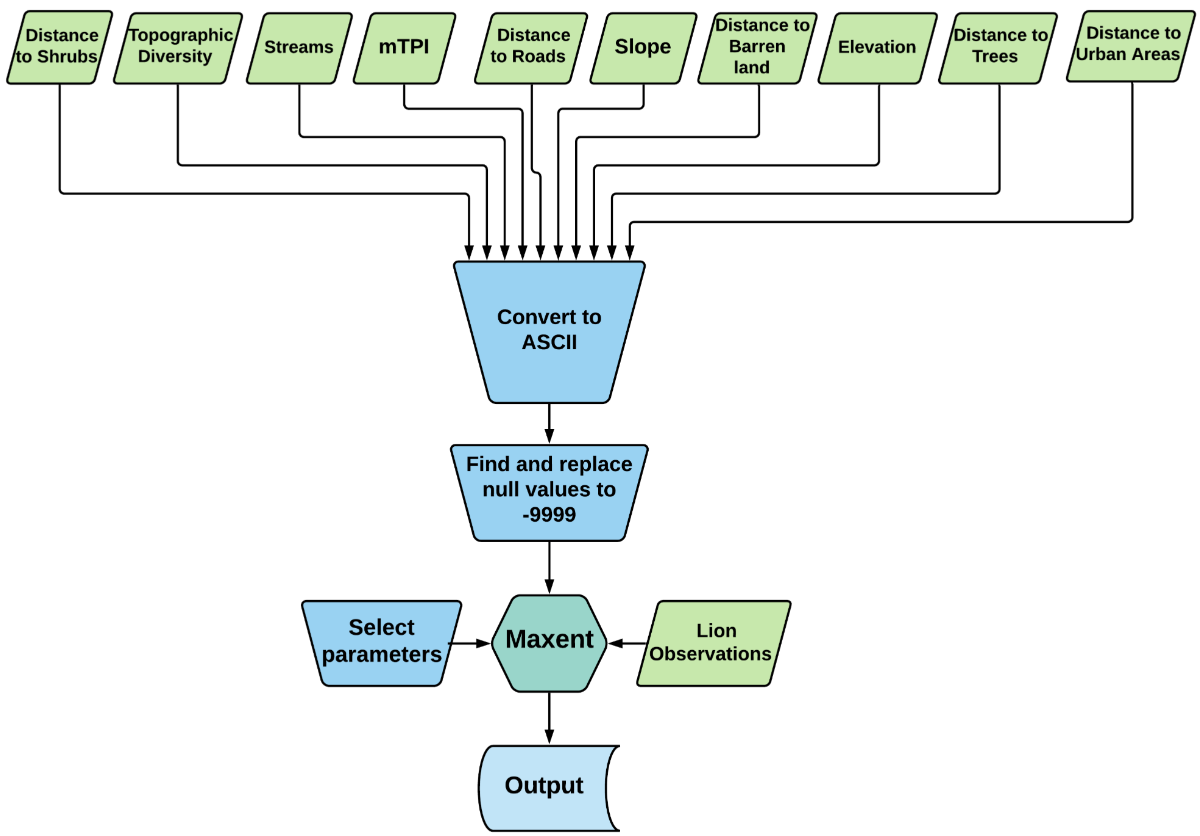
Effective science communication is one of TNC's top priorities. Since recently acquiring JLDP in 2017, TNC has made great strides towards navigating new ways for the community to be engaged with the exciting conservation work on JLDP. To communicate the scientific findings from this project, we have created a short film for The Nature Conservancy to use as an educational tool to help in their mission to engage local community schools with JLDP and the science being conducted there. This film illustrates our research discoveries and explores the role of JLDP in science communication, conservation, and habitat connectivity (Appendix 13).

Short Film Overview

This short film will be focused on our research, the significant role of JLDP in conservation, and the importance of habitat connectivity. The main goals for our team in producing the film were as follows:

- Develop an educational film to convey the conservation importance of JLDP and the opportunities for scientific discovery on the preserve.
- Discuss the elements of our project's exploration on mountain lion movement in Central California to enhance familiarity with terms such as "habitat connectivity."
- Educate and inspire the local community - specifically local middle school and high school students.

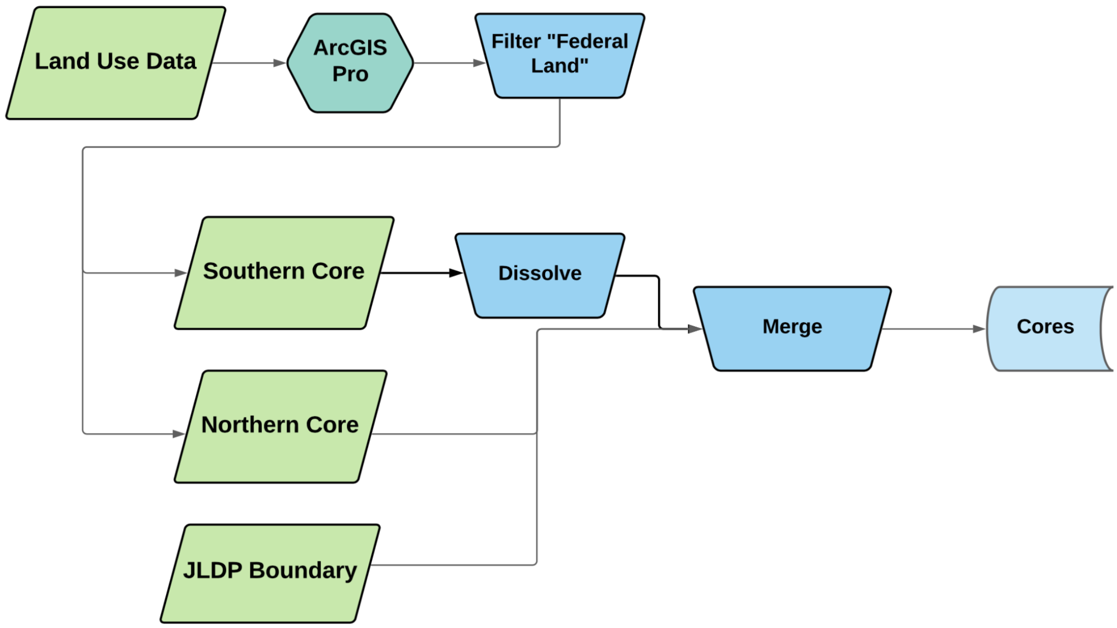
Appendix



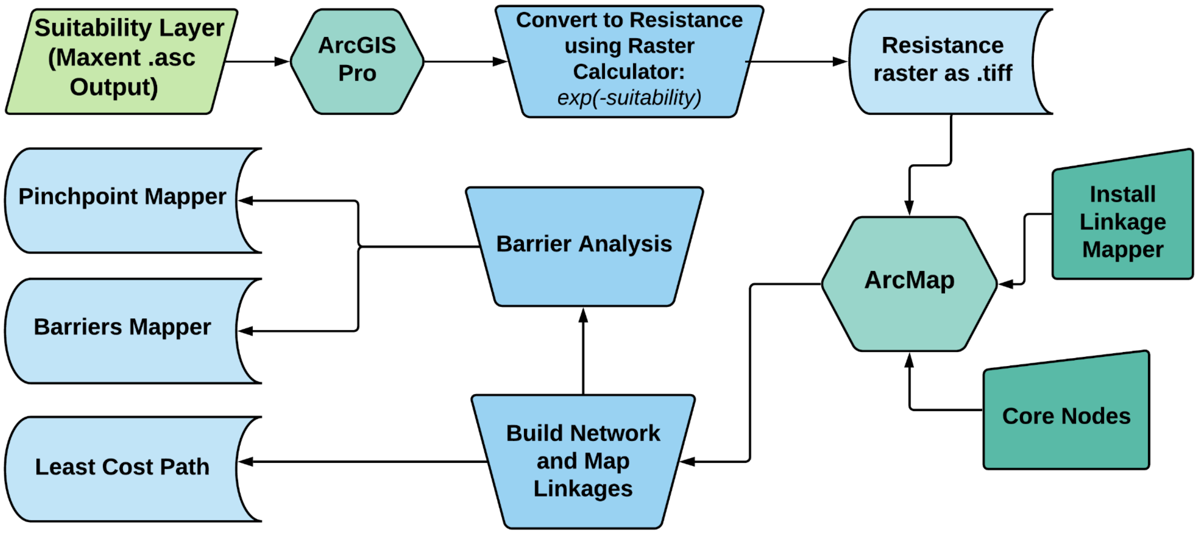
Appendix 1. Maxent workflow. Maxent model workflow (top to bottom) beginning with the input variables from the data acquisition workflow to be converted to ASCII files. Next, find and replace all null values to -9999 for Maxent software ease of use, then load them into Maxent. Utilizing the Maxent GUI, select the parameters described in the methods and load the lion observation data before running the program for a suitability output.

Dataset	Source	Date created	Short description
Elevation	NASA | USGS | JPL-CalTech	2000	Elevation of the central/southern SoCal coast pulled from SRTM satellite imagery
Slope	NASA | USGS | JPL-CalTech	2000	Slope derived from Elevation data pulled from SRTM satellite imagery
Landform	Conservation Science Partners	2006-2011	The SRTM Landform dataset provides landform classes created by combining the Continuous Heat-Insolation Load Index (SRTM CHILI) and the multi-scale Topographic Position Index (SRTM mTPI) datasets (Theobald, 2015).
Multi-scale topographic position index (mTPI)	Conservation Science Partners	2006-2011	mTPI distinguishes ridge from valley forms. It is calculated using elevation data for each location subtracted by the mean elevation within a neighborhood (Theobald, 2015).
Topographic diversity (TD)	Conservation Science Partners	2006-2011	Topographic diversity (D) is a surrogate variable that represents the variety of temperature and moisture conditions available to species as local habitats. It expresses the logic that a higher variety of topo-climate niches should support higher diversity (especially plant) and support species persistence given climatic change (Theobald, 2015).
Streams	CalFish	2016	Dataset includes polyline features for entire stream systems in California.
California Roads	US Census	2021	Major highways within California.
Landcover	CalFire	2015	Land use/land cover (LULC) of California represented in large categories including: shrub, forest, barren and urban.

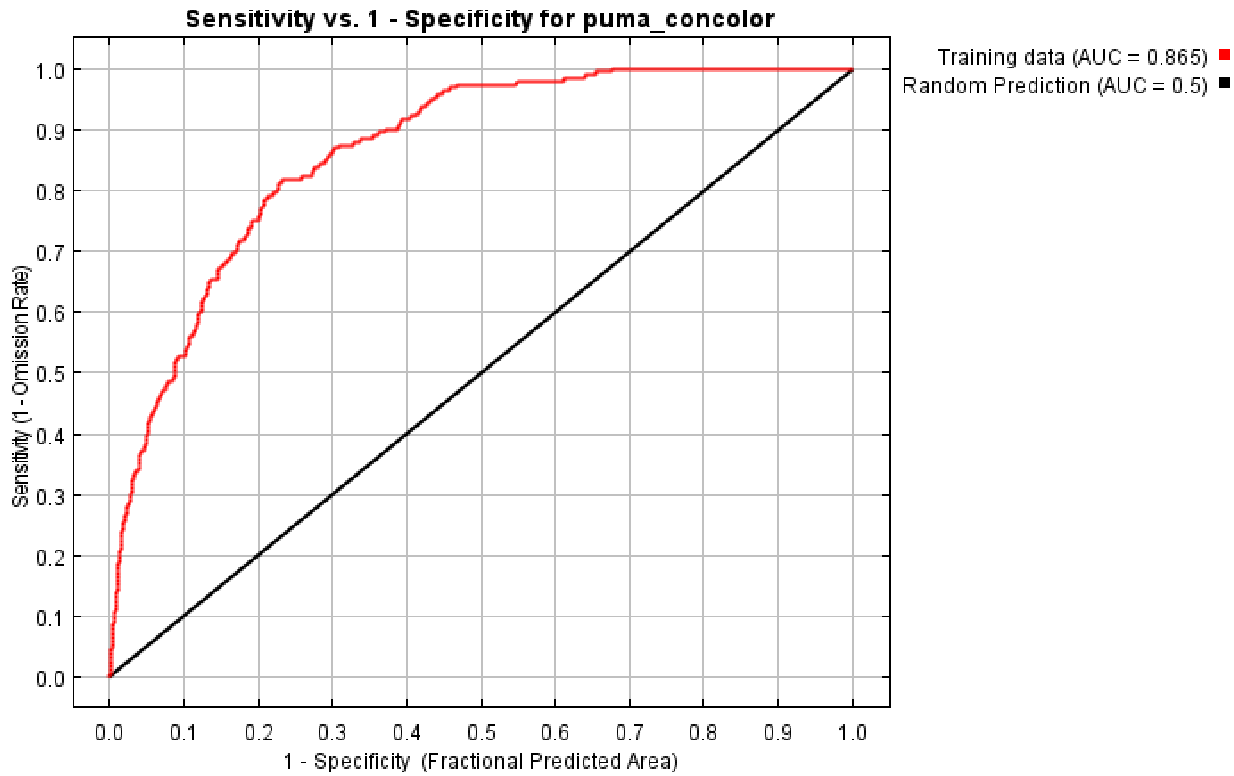
Appendix 2. Regional Data Sources and Description. Datasets used to derive variables for further analyses described as: dataset name, source of dataset, when the data was created, and a short description of what the data contains.



Appendix 3. Core Habitat workflow. Core habitats for circuitscape analysis were produced using the land use dataset as well as the boundary of JLDP. Layers were filtered and dissolved to produce a final attribute table with three columns, specific to the three cores.



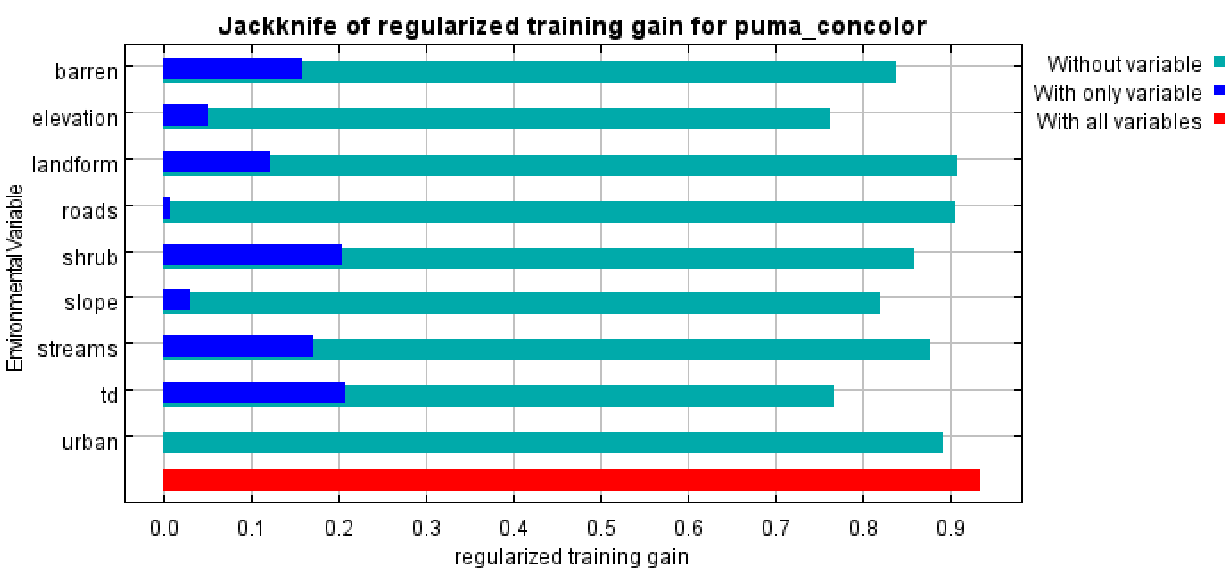
Appendix 4. Circuitscape and Resistance Layer workflow. Maxent suitability output (.asc file format) was dragged into ArcGIS Pro where it was converted to a resistance layer by using the Raster Calculator tool and a negative exponential function. This was exported as a .tiff into ArcMap, where the Linkage Mapper toolkit needs to be installed in order to use Circuitscape. The core nodes were uploaded and the Build Network and Map Linkages tool in the Linkage Mapper toolkit was run. This tool gives the output for the least cost path, and is needed to perform a barrier analysis using the Barrier Mapper and Pinchpoint Mapper tools.



Appendix 5. ROC Curve. Maxent receiver operating characteristic (ROC) curve after removing trees, streams, and mpti environmental variables. The training data used to fit the model has an area under the curve (AUC) value of 0.815, where the random prediction AUC is 0.5.

Variable	Percent contribution	Permutation importance
shrub	26.4	20.4
elevation	15.6	18.8
td	13.9	24.9
slope	9.5	12
barren	9.2	12.2
landform	8.9	1.9
streams	8.5	4.6
roads	5.3	2.6
urban	2.6	2.6

Appendix 6. Variable Contributions. Maxent percent variable contributions table after removing trees, streams, and mpti environmental variables. TD represents topographic diversity. Percent contribution is the contribution of each variable defined by the path Maxent used to get an optimal solution. Permutation importance removes the bias in Percent contribution.

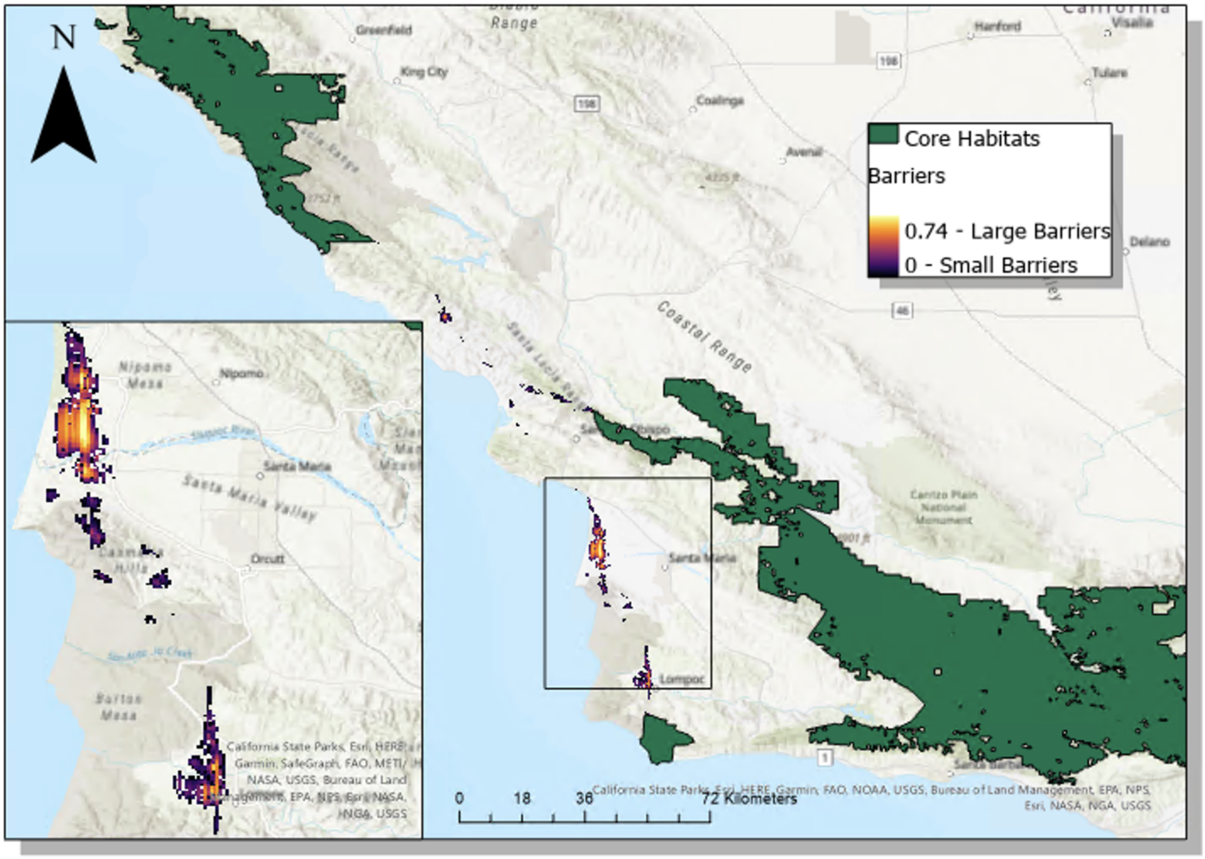


Appendix 7. Jackknife Test of Variable Importance. The environmental variables are listed on the y-axis and the regularized training gain (model contribution) on the x-axis.

Dark blue bars represent the contribution of each individual variable with only that variable present, and the green as the model with all other variables except that one. The red bar at the bottom represents the model contribution of all variables together.

To Core	**From Core**	**CWD to Euc Ratio (Community)**	**CWD to Euc Ratio (Collared)**	**CWD to Resistance Ratio (Community)**	**CWD to Resistance Ratio (Collared)**
Big Sur	*JLDP*	0.66	0.95	107.3	168.4
JLDP	*Los Padres*	0.57	0.89	78	97
Los Padres	*Big Sur*	0.63	0.89	143.4	132.7

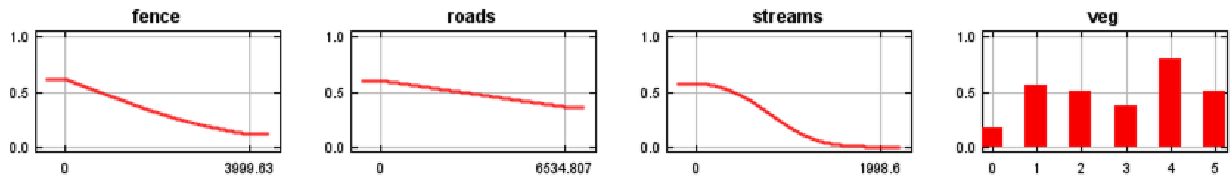
Appendix 8. Least Cost Path Statistics. Data table output from Build Network and Map Linkages tool determining the least cost path in Circuitscape. Left to right: which resistance layer was used, to and from which cores the path led, the cost weighted distance (CWD) to euclidean distance ratio and the cost weighted distance to the resistance metric ratio.



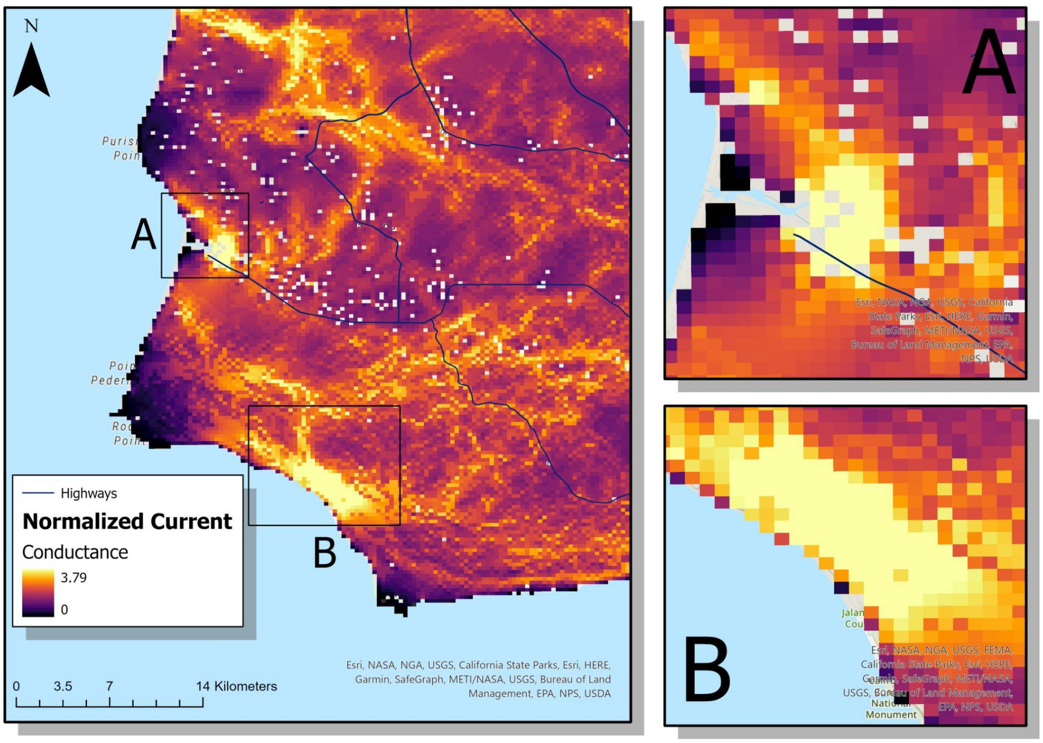
Appendix 9. Barriers to Resistance. Calculated with community science data, the red depicts areas of high barriers to connectivity. Greater barriers are found in urban areas including Lompoc and Santa Maria.

Variable	**Percent Contribution**	**Permutation Importance**
Vegetation	82.1	33.9
Fences	7.7	19.6
Streams	6.7	39.9
Roads	3.5	6.6

Appendix 10. JLDP Maxent Output. Table depicting the Maxent suitability output for each variable and its percent contribution and permutation importance.



Appendix 11. JLDP Response Curves. The response curves show how the Maxent output is affected by each individual environmental variable.



Appendix 12: Locations for Focused Conservation Efforts. The left describes a focused map from the regional omniscape results zoomed in on JLDP, Lompoc and Vandenburg areas. Map A is focused on Surf Beach and the coastal corridor to the west of Lompoc. Map B focuses near Jalama just northwest of the preserve.

Appendix 13: Film Elements

Audience: TNC is developing its science communication and educational programs for JLDP, and creating meaningful interactions with the local school districts is one of its top priorities. As such, this film will be utilized as a part of the proposed curriculum for local middle and high school students as a means to familizare them with JLDP and its mission, instill a sense of pride and awe for this unique place so close to these communities, and inspire future generations with a passion for conservation planning and management.

Message: JLDP was recently acquired by TNC and is a biodiversity hotspot that may act as a crucial area of wildlife refuge. Understanding its role in the greater Central Coast regional environment will help TNC better inform its conservation management plans. As top predators, mountain lions play a vital role in the health of an ecosystem and TNC wants to highlight the importance of their conservation.

Plot and Conflict: Using mountain lions as an umbrella species, this film will lay out how urban sprawl and fragmentation have left the species dispersed and how JLDP can act as a place of refuge and may potentially be an important node of connectivity within the Central Coast region. Additionally, there is much more research that needs to be done in order to understand exactly how mountain lions are being impacted today and what conservation management strategies will be the best for preserving the species as a whole. In essence, the conflict is both what we know about urban sprawl and its impacts on mountain lions as well as the unknowns surrounding this native species.

Resolution: Creating wildlife preserves like JLDP are crucial for providing protected habitat and resources for wildlife species, including mountain lions. Understanding how JLDP and its surrounding areas can play a role in mountain lion connectivity will be essential for informing management and protecting important areas for mountain lions and other species to migrate through and avoid human threats. Using the results from our Group Project in addition to future research, TNC will be able to develop the most appropriate conservation management strategies for both mountain lions and other critical species.

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