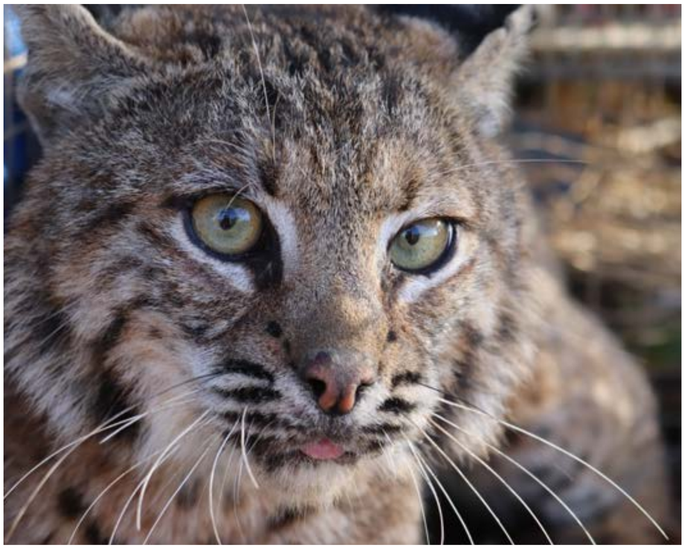

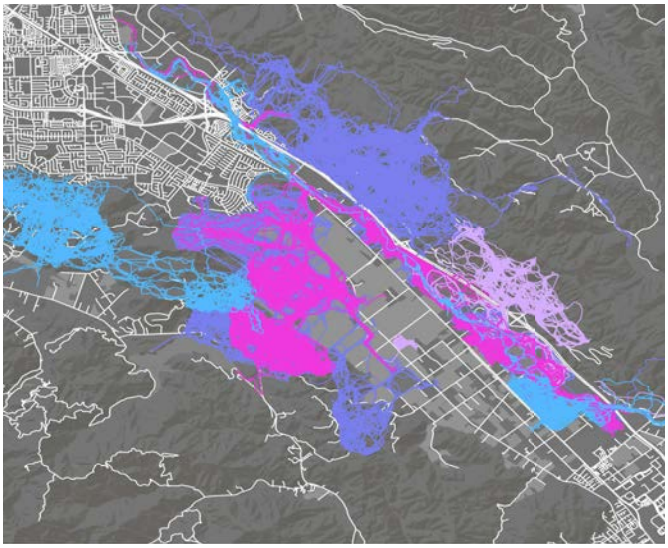

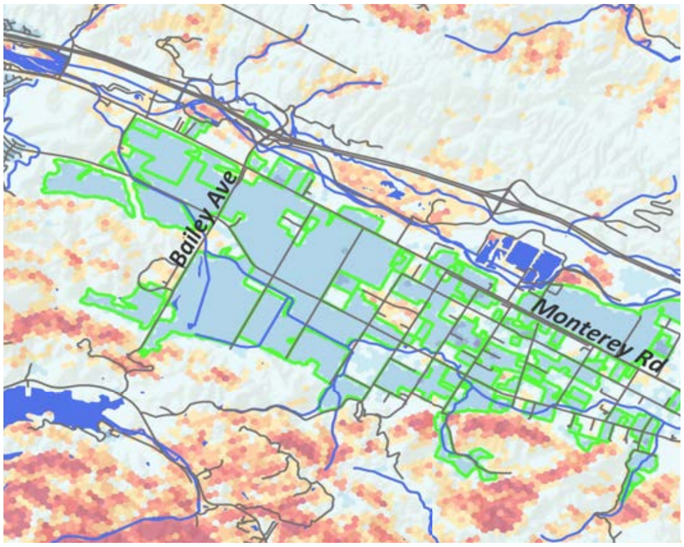

COYOTE VALLEY BOBCAT HABITAT PREFERENCE AND CONNECTIVITY REPORT

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PENINSULA OPEN SPACE TRUST
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JUNE 2019

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TECHNICAL REPORT PREPARED FOR

Peninsula Open Space Trust and
Santa Clara Valley Open Space Authority
June 30, 2019

ACKNOWLEDGMENTS

We would like to thank the following individuals for their work that ensured the success of this study:
Neal Sharma, Peninsula Open Space Trust
Galli Basson, Santa Clara Valley Open Space Authority
Stephani Matsushima, Environmental Studies Department, UCSC
Tanya Diamond and Ahiga Snyder, Pathways for Wildlife
Matthew S. Rogan, Ph.D. Candidate, University of Cape Town, South Africa
Barry Nichols, Ph.D. Candidate, Center for Integrated Spatial Research, UCSC
Justin Suraci, Ph.D., Environmental Studies Department, UCSC
Mercer Lawing, Caging Bobcats, Barstow, California
Shawn Lockwood, Santa Clara Valley Water District
Staff at Santa Clara County Parks

FUNDING

We would like to thank the following funders for supporting this study:
Moore Foundation
Peninsula Open Space Trust
California Department of Fish and Wildlife
Santa Clara Valley Habitat Agency
Santa Clara Valley Open Space Authority
Western Digital

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EXECUTIVE SUMMARY

The San Francisco Bay Region is among the most important conservation areas across the United States (Stein et al. 2000). Yet this region also faces imminent threat from rapid urbanization (Santa Clara Valley Open Space Authority and Conservation Biology Institute 2017). Urbanization causes habitat loss and fragmentation and impedes wildlife movement and gene flow (Riley et al. 2006, 2014a, 2014b, Keyghobadi 2007, Balkenhol and Waits 2009, Jackson and Fahrig 2011, Lee et al. 2012). The Coyote Valley, located within the San Francisco Bay Region, offers a "last chance" for functional habitat connectivity between the Santa Cruz Mountains and Diablo Range (Santa Clara Valley Open Space Authority and Conservation Biology Institute 2017). Numerous wildlife species inhabit the Coyote Valley (Diamond and Snyder 2016) despite its extensive fragmentation by roads, agriculture, and residential areas. Further, Coyote Valley is under immense pressure to increase urban development which could effectively isolate wildlife populations in the Santa Cruz Mountains from the larger connected Diablo Range (Santa Clara Valley Open Space Authority and Conservation Biology Institute. 2017). This study aims to provide conservation agencies and other stakeholders in Coyote Valley with the data and scientific insights needed to preserve ecological connectivity across the Coyote Valley.

The overarching objective of this study is to document the movement of a highly mobile mesocarnivore species, the bobcat (*Lynx rufus*), as a proxy for understanding existing habitat connectivity (Litvaitis et al. 2015) throughout the Coyote Valley, and identify the habitat features that facilitate or impede animal movement across the landscape. We captured, GPS-collared, and monitored 26 bobcats in the Coyote Valley from June 2017- February 2018. The GPS-collars collected data at 5-minute intervals. From these high-resolution data, we modeled how bobcats select habitat in the Coyote Valley and how they respond to human disturbance. We also used these data to identify areas where bobcats cross major roads. In addition to the spatial locations of bobcats, we gathered samples for genetic analysis. The genetic samples provide early insights into the degree of genetic connectivity of bobcats in Coyote Valley (Smith et al. *in review*). Finally, we recorded sources of mortality for bobcats in the valley.

We collected 496,104 GPS-locations for the 26 bobcats captured and monitored. While bobcats are a generalist, highly adaptable species, these individuals overwhelmingly selected trees and shrubs rather than open grassy areas and agricultural fields. In particular, bobcats avoided row crops and areas within 100 meters of residential neighborhoods.

Vehicle collisions were the leading source of mortality for Coyote Valley bobcats. We recorded 19 instances of bobcats killed while crossing roads. Nevertheless, GPS data revealed nearly 3,000 instances of bobcats successfully crossing major roads. We found that the crossings typically occurred in topographical depressions and stream beds where natural vegetation (e.g., trees and shrubs) was prominent on both sides of the road. They often used culverts to safely pass under roads. In contrast to research from elsewhere in California (Riley et al. 2006, 2014b, Delaney et al. 2010), bobcats routinely crossed Highway 101 safely, likely because of the presence of well-vegetated underpasses. Conversely, crossing Monterey Road was especially deadly; its concrete median topped with fencing and lack of wildlife-friendly culverts may trap animals on the road during attempted crossings.

We tested ten bobcats that died for anticoagulant rat poison exposure. All ten of the bobcats we tested were exposed to these ubiquitous rat poisons. Rat poisons are commonly found in California's wildlife, and can kill numerous wildlife species and increase bobcat susceptibility to notoedric mange (Riley et al. 2007, Serieys et al. 2013, 2015a, 2018, Fraser et al. 2018). These poisons are more harmful for canids than felids (Erickson and Urban 2004), and are one possible explanation for why we did not detect gray foxes during fieldwork, which have previously been documented in the Coyote Valley (Diamond and Snyder 2016; see suggestions for future research below).

Based on the findings of this study, we make the following management recommendations and suggestions for future research:

- **Habitat restoration.** Native vegetation that provides cover will be instrumental in facilitating wildlife movement between the Santa Cruz Mountains and the Diablo Range. It also provides shelter and resting areas for numerous species, including bobcats and their prey (e.g., small rodents and hares). We recommend restoring both faster growing native shrubs so as to provide immediate cover as well as slower growing native trees to provide long term cover in corridors crossing the valley and intersecting major roads where culverts or underpasses already exist.
- **Repair culverts and underpasses to ensure "wildlife friendly" road-crossing locations.** Where there are already culverts that are feasible for wildlife use to cross major roads, ensure they remain clear of debris and passable by wildlife. In particular, we recommend retrofitting the Fisher Creek culvert under Monterey Road to remove standing water and increase suitability for wildlife use.
- **Add under or over passes to Monterey road while simultaneously restoring more habitat along Monterey road.** Monterey Road is currently a pinch point for animals trying to get from one side of the valley to the other. The only potential viable crossing is at Fisher Creek. To ensure the long-term value of the Coyote Valley for wildlife connectivity, their needs to be more viable crossings. This could be achieved by protecting and restoring habitat south of Fisher Creek and adding more crossing structures to Monterey Road.
- **Funnel wildlife to safe road-crossing points**. Fencing installed along roads, coupled with restored vegetation, can guide wildlife to safe crossing points and prevent indiscriminate crossing attempts, particularly on dangerous roads such as Monterey Road and Highway 101.
- **Reduce risk of collisions on Monterey Road.** We recommend removing the metal fencing atop the concrete median, and also remove or reduce the concrete median, that bisects Monterey Road.
- **Outreach campaigns that reduce rodenticide use.** Rodenticides kill wildlife across California, including bobcats, coyotes, gray foxes, mountain lions, and numerous avian predators. They are particularly common in agricultural and residential areas. Targeted "break the poison chain" campaigns directed at local residents and agricultural operators could reduce the pervasiveness of the compounds on the landscape.
- **Future research: a robust genetic survey**. Conduct a robust study investigating potential genetic segregation of populations separated by Monterey Road and Highway 101. Carnivore species that exist in low-density populations (such as bobcats) are excellent indicator species of genetic processes on the landscape. We recommend opportunistic sample collection from roadkill or other mortalities, targeting a sample size of approximately 20 individuals sampled on either side of Highway 101 and/or Monterey Road.
- **Future research: gray foxes.** This study was initially conceptualized to include gray fox habitat preference and movement ecology, but we were unable to detect foxes once trapping commenced. The apparent absence of gray foxes when they were recently present may be linked with infectious disease, rodenticides, poor habitat quality, or competitive exclusion by coyotes. Noninvasive surveys aimed at collecting fox-specific data may help pinpoint the cause of the apparent decline in Coyote Valley foxes. For example, pathogen testing on fecal samples opportunistically collected could reveal infectious disease dynamics that may have precipitated a population decline.

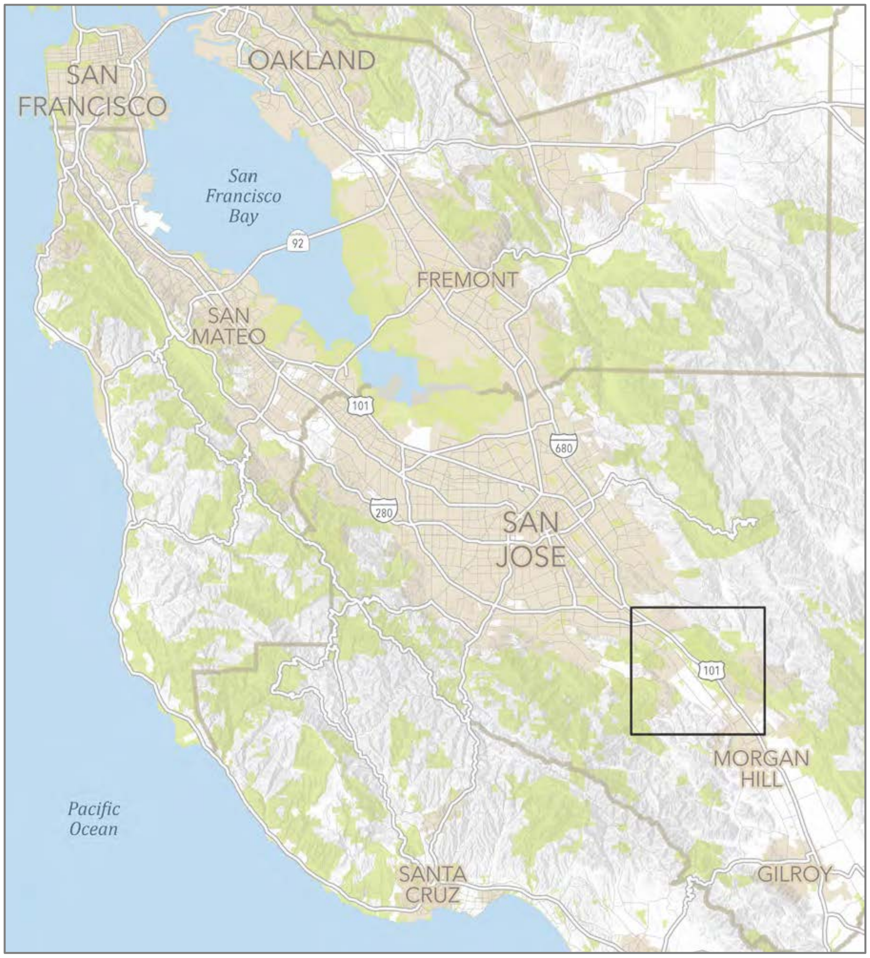

Figure 1. *Map of the San Francisco Bay Region. Coyote Valley, framed with the black square, is situated between the Cities of San Jose and Morgan Hill.*

INTRODUCTION

Coyote Valley

The San Francisco Bay Region (Figure 1) is ranked among the six most important conservation regions within the U.S. (Stein et al. 2000). Yet the region faces imminent threats from increased urbanization, fragmentation, and road and high-speed rail development. Front and center to this rapid-paced development, Coyote Valley (Figure 1) offers a "last chance" landscape of habitat connectivity for wildlife (Santa Clara Valley Open Space Authority and Conservation Biology Institute 2017). The Coyote Valley encompasses approximately 7,400 acres (roughly 30 km^2) situated in Santa Clara County between the Cities of San Jose and Morgan Hill. Coyote Valley is identified as a significant wildlife linkage between the Santa Cruz Mountains and the Diablo Range (Santa Clara Valley Open Space Authority and Conservation Biology Institute 2017). Despite the expectation that the Coyote Valley provide an essential bridge between the Santa Cruz Mountains and Diablo Range, Coyote Valley itself is already fragmented, largely by row crop and orchard agricultural fields that comprise approximately 70% of the Valley floor. Other human land uses include commercial, residential, and altered open areas (i.e., golf courses and school yards). Major roads such as Highway 101 and Monterey Road also bisect the Valley. The natural areas that remain are a mix of riparian habitat at the center of the Valley floor, sandwiched by oak woodland with grassland savannah in the western foothills, and serpentine habitat in the eastern foothills. Despite the small size, development, and fragmentation, Coyote Valley is host to numerous wildlife species, including bobcats, gray fox, racoons, and coyotes (Diamond and Snyder 2016). Many land conservation organizations and resource agencies are investing resources towards studying and protecting habitat in the Valley. Critically, conservation organizations need data on wildlife movement and habitat use to help inform land acquisition, restoration, and land use decisions.

The Coyote Valley Linkage Assessment Study, completed in 2016, used remote camera data to document wildlife movement along the Fisher Creek and Coyote Creek corridors (Diamond and Snyder 2016). Due to the limitations of non-invasive techniques (e.g. remote cameras or scat/tracking surveys) to document fine-scale wildlife movement, Diamond and Snyder (2016) recommended a detailed telemetry study to monitor wildlife movement across the landscape. Given the area is already fragmented by various types of human land uses, fine-scale wildlife movement data would provide essential connectivity and habitat suitability data in the region before even more extensive habitat loss, fragmentation, and modification leads to irreversible population fragmentation.

Connectivity and wildlife

Habitat loss and modification associated with urbanization is not only the principal threat to biodiversity globally, but also presents a variety of novel stressors to wildlife populations (Riley et al. 2006, Keyghobadi 2007, Balkenhol and Waits 2009, Jackson and Fahrig 2011, Lee et al. 2012, Wilmers et al. 2013, Riley et al. 2014a, 2014c, Serieys et al. 2018). Roads and other urban infrastructure cause habitat loss and fragmentation, and also impede individual movement, fitness, and consequently gene flow (Riley et al. 2006, 2014a, 2014c, Keyghobadi 2007, Balkenhol and Waits 2009, Jackson and Fahrig 2011, Lee et al. 2012). Roads themselves are direct sources of mortality for wildlife, further contributing to genetic erosion that occurs as a result of habitat fragmentation (Balkenhol and Waits 2009, Jackson and Fahrig 2011, Riley et al. 2014a). The maintenance of functional habitat connectivity has thus become a central goal to conservation globally to mitigate the effects of anthropogenic development and climate change (Crooks and Sanjayan 2006, Chazal and Rounsevell 2009, Crooks et al. 2011, LaPoint et al. 2015).

Studies in southern California focused on a variety of taxa (carnivores, birds, reptiles and amphibians) have found that major freeways and expansive urbanization pose threats to numerous species beyond direct loss of suitable habitat (Riley et al. 2006, 2014c, Delaney et al. 2010, Serieys et al. 2015b). In particular, Highway 101, that spans the State from southern to northern California, is widely acknowledged as a significant movement barrier for multiple wildlife species in southern California. Both genetic and telemetry studies on bobcats, coyotes (Riley et al. 2006), and mountain lions (Riley et al. 2014c) demonstrated that this freeway, although less than 1 km in width, is such a pronounced movement barrier that it drives social change that exacerbates genetic erosion for the three species (Riley et al. 2006, 2014c, Serieys et al. 2015b). The extent to which sprawling urbanization has equal effect in the San Francisco Bay Region is less well-known. Importantly, in regions of the State where land acquisition is a key approach to the maintenance of biodiversity conservation and habitat connectivity, evaluating the role of anthropogenic landscape features and habitat modification on wildlife movement a local scale is essential to targeted conservation efforts.

OBJECTIVES AND METHODS OVERVIEW

We used a landscape-species approach (Sanderson et al. 2002, Redford et al. 2003) as a means to identify specific areas within Coyote Valley that influence landscape connectivity and highlight potential threats to species from human activity. To implement this approach, we chose a mesocarnivore, the bobcat (*Lynx rufus*), as our focal species, given their relative sensitivity to habitat fragmentation (Crooks 2002, Ordeñana et al. 2010) and their high mobility and large resource requirements (Litvaitis et al. 2015). Their need for large areas to find sufficient food and mates means that in an area fragmented by human land uses, bobcats have an inherent need to move between fragmented habitat and thus also frequently cross roads. By studying their movements, they indicate habitat quality, connectivity, and landscape features that can drive wildlife movement (Riley et al. 2003, 2006, 2014a, Litvaitis et al. 2015). Further, as carnivores, they are vulnerable to the accumulation of pathogens and toxicants that spillover from urban areas into nearby patchy habitat (Riley et al. 2007, 2010, 2014b, Serieys et al. 2013, Carver et al. 2016). Accordingly, bobcats are a landscape species that indicate habitat quality, threats to wildlife populations, and act as sentinels of ecosystem health.

Our objectives were:

1. ***Monitor fine-scale bobcat movement in and around the Coyote Valley floor to Identify the relative importance of natural and human-modified landscape features that influence bobcat movement.***

To meet this objective, we captured and GPS-collared 26 bobcats during both the dry and wet seasons. We collected fine-scale (5-minute) GPS-locations for each bobcat as they traversed the landscape throughout the 24-hour diel cycle. We used the GPS-collar data to estimate their degree of mobility (i.e., home range size). We then used a standard spatial modelling approach (step-selection functions) to evaluate the relative importance of natural landscape and human land use features (e.g. vegetation, slope, proximity to roads and water, housing development, etc.) in determining bobcat movement throughout the Coyote Valley. We performed these analyses using all movement data together (independent of season), and next partitioned the data by season (wet, dry) to inform potential seasonal differences in bobcat movement. We used the results of our spatial habitat selection models to map bobcat probability of use for habitat across the Coyote Valley. These data are critical to guide land acquisition efforts that will protect functioning wildlife corridors and inform habitat restoration.

2. ***Evaluate the role of roads as barriers to movement: identify the frequency of road crossings, and the attributes of safe, and dangerous, crossing points.***

We used the fine scale (5-minute) movement data to assess where, the frequency, and how (i.e., via culverts, underpasses, etc.) bobcats crossed arterial roads, including Monterey Road, Bailey Avenue, Santa Teresa Boulevard, Bernal Road, Metcalf Road, and Highway 101. We identified and mapped both wildlife-friendly and dangerous road-crossing hotspots and describe features of prominent road-crossing areas. These data are critical to the design and implementation of road and rail projects that facilitate safe wildlife movement.

3. ***Asses contributors to bobcat mortality in Coyote Valley.***

We used telemetry to monitor the fate of GPS-collared bobcats by actively tracking them on a weekly basis (when possible). Additionally, during daily fieldwork operations, we opportunistically collected dead, untagged bobcats. We performed necropsies on all individuals that died during the study period to identify sources of mortality. We collected a variety of tissue samples from all individuals and performed standard anticoagulant rat poison testing to assess whether ubiquitous rodenticides increase bobcat vulnerability to death due to human activities.

For a detailed description of fieldwork methods and statistical analyses, please refer to Appendix A.

STUDY FINDINGS AND DISCUSSION

Sampling, GPS-collaring, and Tracking

We captured and GPS-collared 26 bobcats (Tables 1 and Appendix B1, Figures 2-3). In one case, the collar fell off within one day (see below). We therefore obtained tracking data for 25 individuals. Eight unique bobcats were captured during the dry season (male, n = 5; female, n = 3; adult, n = 7; juvenile, n =1). The remaining 18 unique individuals were captured during the wet season (male, n = 11; female, n = 7; adult, n = 5; juvenile, n = 13). We also recaptured and replaced the GPS-collar for two adult females (B03F and B05F) and one adult male (B07M), but lost track of the recollared male shortly after he was recollared. In the case of six juveniles, they were expected to experience imminent growth spurts, and thus we fit thin cotton spacers within the collar belting to assure collars fell off within a three-month period (see Appendix A for detailed methods). GPS-collared individuals were tracked between three to 437 days (Appendix B1), with an average of 160 tracking days (5.3 months) across the 25 individuals (standard deviation [sd] = 118 days; median = 139 days). For three individuals we had very little tracking data (three, seven, and 13 tracking days) because one collar fell off prematurely, one collar failed, and the bobcat was hit by a car (respectively). Due to the short interval of data collection for these individuals, they were discarded from home range assessments. The individuals for which we <10 days of data were also eliminated from habitat selection analyses. Overall, we collected robust GPS-tracking data for 23 individuals over a period of 4,054 days (number of days tracked summed across all bobcats). We collected 496,104 GPS-locations that we used in downstream statistical analyses described below.

Bobcat home ranges in Coyote Valley

A primary reason that we selected bobcats as our focal species is their high mobility. Bobcats are considered solitary and territorial and generally exist in low density populations (Crooks 2002, Riley et al. 2010). Home range dynamics are associated with prey base, mate availability, the ability of wildlife to find secure resting and denning areas, animal age and sex (Riley et al. 2003, Bateman and Fleming 2012, Wilmers et al. 2013, Šálek et al. 2015). Male bobcats typically establish home ranges that overlap multiple female home ranges. Males and females typically exclude one another in their established territories (Riley et al. 2010). As a proxy for mobility, we estimated (95% kernel density estimate [KDE]) home range sizes for the adult bobcats monitored during the study. Adult males used an average area of 8.5 km^2 (sd = 1.9), while adult females used an average area of 4.6 km^2 (sd = 2.0). Because the time period individuals were monitored (< 1 year), it is likely that we did not detect the full scope of individual home ranges. However, these observed ranges are approximately twice the home range sizes of bobcats in southern California. In Los Angeles, Ventura, and Orange Counties, males use approximately 5–6 km^2, while females use 2–3 km^2 (Riley et al. 2010). It is possible that a lower density of resources in the oak savannah and serpentine habitat contributes to the larger home ranges observed, although the many factors that influence home range size can be complicated and difficult to measure (Benson 2006). However, Coyote Valley, particularly its riparian zones, appears to provide rich, fertile grounds for bobcats. We GPS-collared one lactating female west of Santa Teresa Boulevard on the IBM property. We also GPS-collared an older adult female in the Coyote Creek Parkway that established denning behavior (suggesting she had kittens) just adjacent to the bike path. Thus, despite the amount of human disturbance in the Coyote Creek Parkway and Coyote Valley generally, bobcats can reproduce and establish den sites. Further, in the Coyote Creek Parkway we also captured six juveniles that were approximately six months old, reinforcing that reproduction, a critical component to population viability, occurs in Coyote Valley.

Among the most interesting observations related to Coyote Valley bobcat home ranges was the influence of Monterey Road as a home range boundary. In comparison with other arterial roads in the study area, Monterey Road was a boundary to the home ranges of multiple adults (Figures 2-3) with few individuals with home ranges straddling this major road. In contrast, the home ranges of adults captured both east and west of Monterey Road straddled major arterial roads including Bailey Avenue, Santa Teresa Boulevard, and even Highway 101 (Figures 2-3). Linear features such as roads and urban infrastructure are known to act as barriers to movement and are suggested to be linked with the “pile-up” of territories if the road is a sufficient barrier to movement (Riley et al. 2003, 2006, 2014a). These findings support the hypothesis that Monterey Road is the road that presents the most formidable movement barrier in Coyote Valley.

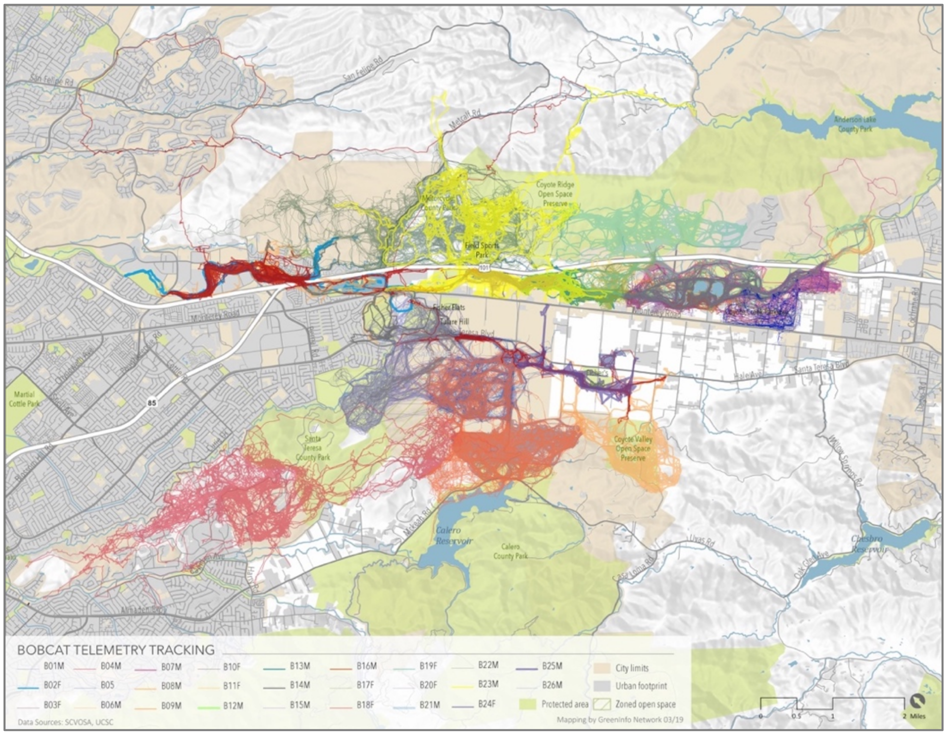

Figure 2. *Map of bobcat movement data collected using GPS-enabled collars in Coyote Valley.*

GPS-collared group	Total	Adult	Juvenile
All tracked bobcats	25	12	13
Male	16	6	10
Female	10	6	4
Mortalities	7	5	2
Collar battery died	7	4	3
Collar fell off	5	0	5
Collar failed	1	0	1
Lost contact prematurely (unknown reasons)	3	1	2

Table 1*. Summary of GPS-collar deployments*

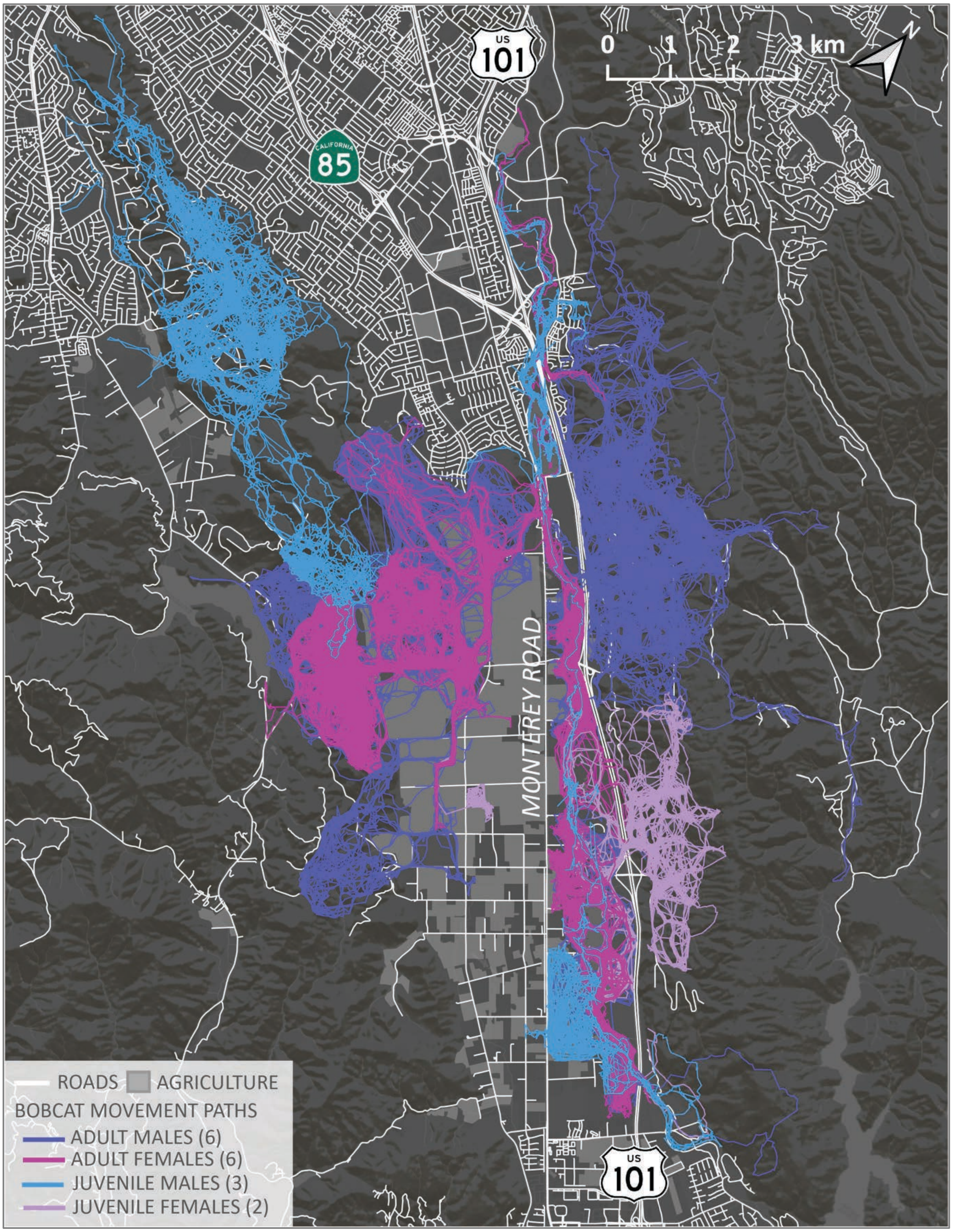

Figure 3. *Map illustrating the degree to which adult home ranges readily, and safely, straddle Highway 101, while few try to straddle Monterey Road. Those with ranges crossing Monterey Road all died (n = 3).*

Habitat selection

We tested the relative importance of natural and human-modified landscape features that influence bobcat habitat selection. We performed step selection functions (SSFs) implemented via generalized estimating equations (GEE), a standard approach in the field of ecology (Thurfjell et al. 2014). SSFs are powerful tools for assessing resource selection by animals as they move across the landscape (Forester et al. 2009, Thurfjell et al. 2014). The general principal is to compare the landscape attributes of each GPS location collected with a GPS-collar ('used' location) with the landscape attributes of 20 random 'available' locations on the landscape that the animal could have chosen instead. We focused on landscape attributes that are of natural biological relevance (i.e., elevation, slope, distance from water, presence of trees, shrubs, and grass), and landscape attributes associated with human development that may exert powerful effects on bobcat choice of landscape as they move across the landscape (i.e., distance from roads, presence of agriculture, housing density; see Appendix A for detailed methods).We first performed the habitat selection analyses with all data collected. Next, we partitioned the data by season and performed the analyses again to evaluate potential seasonal differences in habitat selection given that Coyote Valley has prominent riparian zones where differences in rainfall may influence habitat selection. We report the results of habitat selection models below (e.g., selection coefficient, p-values, robust standard errors, etc.; Tables 2-3, Appendix B2, Figures 4-5).

All models (season-independent, and individual wet and dry season analyses) revealed that bobcats overwhelmingly select movement paths based on the presence of shrubs and trees. The degree of selection for shrubs (primarily coyote brush, *Baccharis pilularis*) and trees (oak savannah and riparian areas) were remarkably apparent even when mapping each individuals' movement data over satellite imagery of Coyote Valley (Figure 6). Bobcats had a strong aversion to row crops and moderate aversion to orchards (Tables 2-3, Appendix B2, Figures 4-7). Row crops in particular provide little-to-no cover as they move across the landscape.

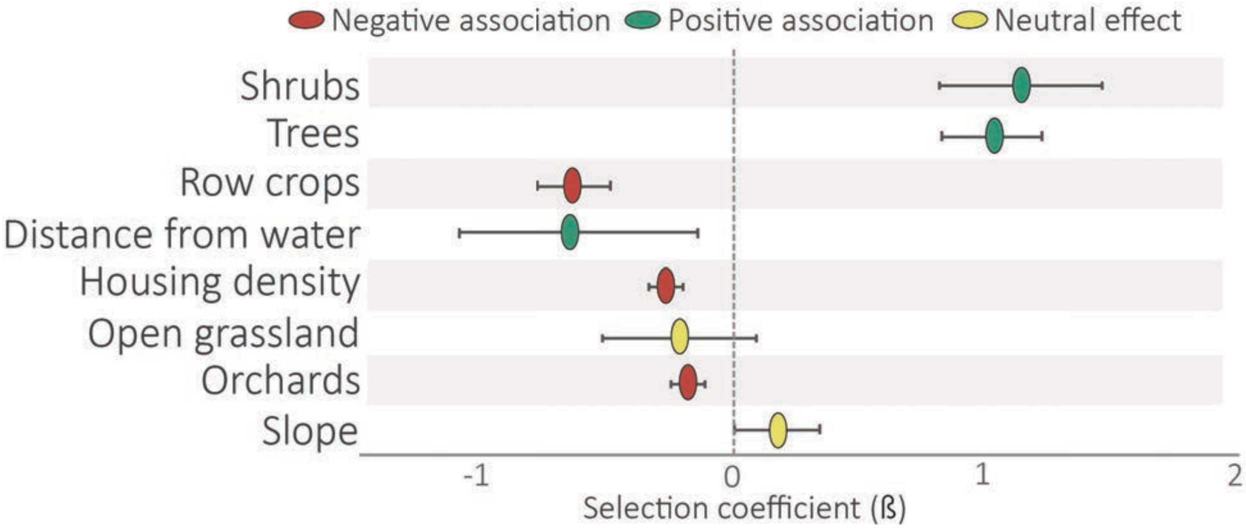

Figure 4. *Illustration of selection coefficients and 95% confidence intervals for landscape variables found to influence habitat preference. Although some variables have neutral effect (yellow), they were identified in the top spatial model. Note that a negative coefficient for water actually implies that bobcats are selecting for water, because "distance to water" was the covariate. As such a negative selection coefficient implies that bobcats are choosing to be closer to water than not.*

The selection for vegetation that provides cover, while avoiding landscapes with little cover (i.e., row crops) is not surprising (Figures 4-7). Bobcats are secretive, ambush predators, and thus the presence of cover is essential to allowing them to cryptically navigate the landscape to find food. Bobcats also avoided orchards, but to a lesser degree than the agricultural fields with low-lying row crops. Orchards still offer moderate cover to bobcats. Within the Coyote Valley, the dominant orchard type are cherries which, even when not actively in fruit, attract numerous prey species (Serieys, personal observation) particularly a favored prey species, ground squirrels (*Otospermophilus beecheyi*, Fedriani et al. 2000, Smith et al. 2018).

With respect to the influence of housing density, we found the strongest effect at a scale of 100-meter buffers around each location, after testing for the effect of housing density at a scale of 50–1000 meters at 50–100 meters increments. GPS-collared bobcats thus select habitat even within close proximity to residential areas (Figures 2-3, 7). However, our analyses indicate that once within 100 meters of residential areas, they exhibit the strongest aversion to residential areas. We observed only two bobcats to navigate residential areas themselves. Both were juveniles (B04M and B19F) that were exploring the boundaries of their home range during apparent dispersal efforts. All other individuals were able to use open space directly adjacent to residential areas, but as seen elsewhere and with other, similar species, this wild felid rarely ventured into highly urbanized areas themselves (Tigas et al. 2003, Dunagan et al. 2019, Serieys et al. 2019).

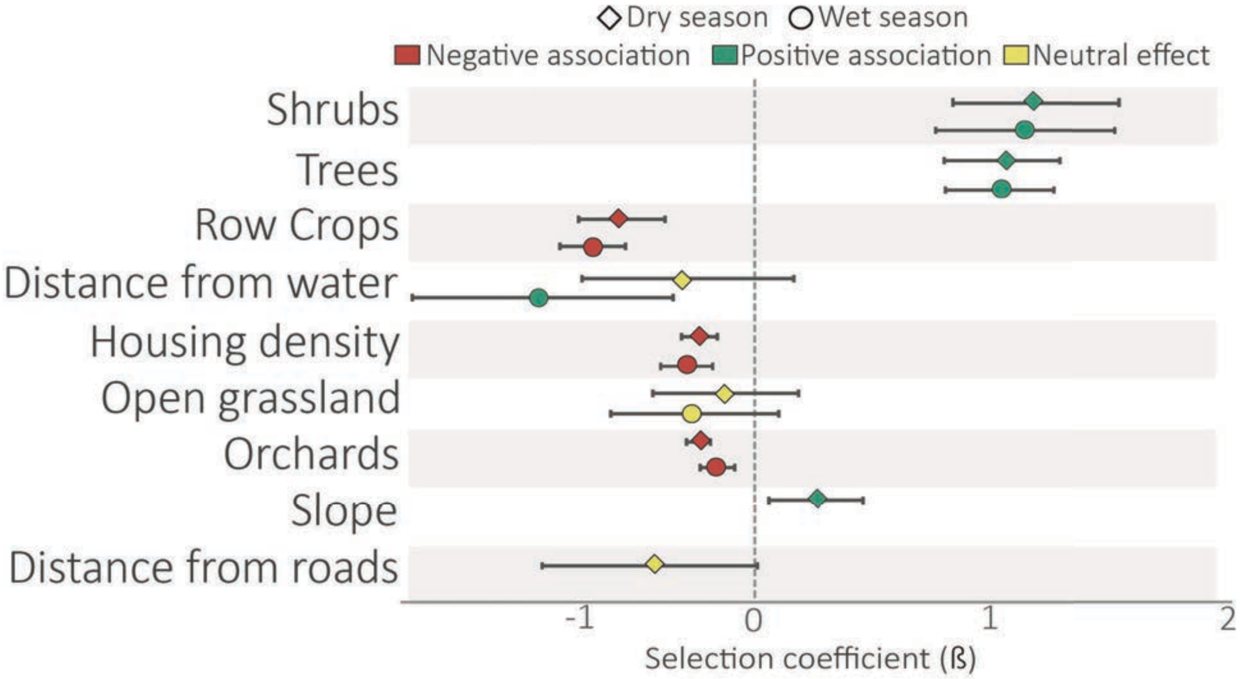

Figure 5. *Selection coefficients and 95% confidence intervals for landscape variables that were identified in the top habitat selection models independently for dry and wet season datasets. Distance from water is measured as the distance from a water body, and thus although the selection coefficient is negative, the association is positive. Where confidence intervals cross zero, the value is not statistically significant even if the parameter is present in the top model fit.*

Covariate	ß estimate	exp(ß estimate)	SE	Robust SE	*p*-value	Lower 95% CI	Upper 95% CI
Shrubs	1.13	3.09	0.02	0.17	**< 0.0001**	0.80	1.45
Trees	1.01	2.76	0.02	0.10	**< 0.0001**	0.81	1.21
Row Crop	-0.64	0.53	0.02	0.07	**< 0.0001**	-0.79	-0.50
Distance from water	-0.63	0.53	0.02	0.24	**0.009**	-1.11	-0.16
Housing density	-0.28	0.75	0.02	0.04	**< 0.0001**	-0.35	-0.21
Open grassland	-0.23	0.79	0.03	0.16	0.136	-0.54	0.07
Orchards	-0.20	0.82	0.02	0.03	**< 0.0001**	-0.26	-0.13
Slope	0.16	1.17	0.02	0.09	0.063	-0.01	0.33
Directional persistence	0.15	1.16	0.01	0.07	0.023	0.02	0.28
Step length	-0.05	0.95	0.02	0.22	0.809	-0.49	0.38
Log(Step length)	0.42	1.52	0.02	0.15	0.005	0.13	0.71

Table 2*. Results from the top habitat selection model performed independent of season. A positive selection coefficient (ß) generally indicates a positive association between selection and the covariate (landscape variable). However, because we measured the influence of water (i.e., streams) as a distance from the nearest water body, a negative value for 'distance from water' indicates a positive association. Habitat covariates that were significant are in bold. Upper and lower 95% confidence intervals (CI) were calculated using the robust standard error (SE). Where confidence intervals cross zero, the parameter is not significant, but it may still be included in the top model. The presence of DIRECTIONAL PERSISTENCE, STEP, and LOG(STEP) correct for the effect of inherent behavioral constraints (see Appendix 1 for more information). Animals tend to move in straight trajectories (DIRECTIONAL PERSISTENCE), whereas STEP and LOG(STEP) control for the ability of an animal to move certain distances within the given time frame and that the strength of their selection may change relative to their distance (or log distance) from various landscape features.*

We detected several seasonal differences in bobcat habitat selection (Tables 3, B2-B3, Figure 5). During the wet season, bobcats selected for closer proximity to water (Tables 3, B2, Figure 5), while during the dry season (Tables 3, B3, Figure 5), proximity to water exerted no influence on bobcat movement. Although this finding may seem counterintuitive, bobcats are not dependent on water sources to obtain sufficient water to support them. In our study area, several GPS collared bobcats occupied areas without perennial water sources. In southern California, the same trend has been observed, leading researchers to conclude that much of the water that bobcats ingest occurs directly when they consume prey (S.P.D. Riley, personal communication). During the wet season, therefore, their selection for proximity to water is likely driven by prey abundance (most likely migratory waterfowl) rather than need for water itself. During the dry season, many streams are dry and would have reduced prey abundance. Another seasonal difference we observed was that bobcats select for steeper slopes during the dry season compared with the wet season. During the hot summer dry season, bobcats likely seek shelter in cooler drainages with steeper slopes.

Finally, although we expected that bobcats would avoid roads, we found that during the dry season there was a very marginal selection for proximity to roads (Tables 3, B3, Figure 5). The biological reason for this trend is unclear, and the trend may even be spurious. However, it is possible that because bobcats select for proximity to low lying water areas during the wet season but not during the dry season, they may use the lower-lying flat roads to navigate marginally more during the dry season. Alternatively, during initial analyses, we detected that adults have a stronger preference for proximity to roads than juveniles, possibly because they patrol roads at the boundary of their home range.

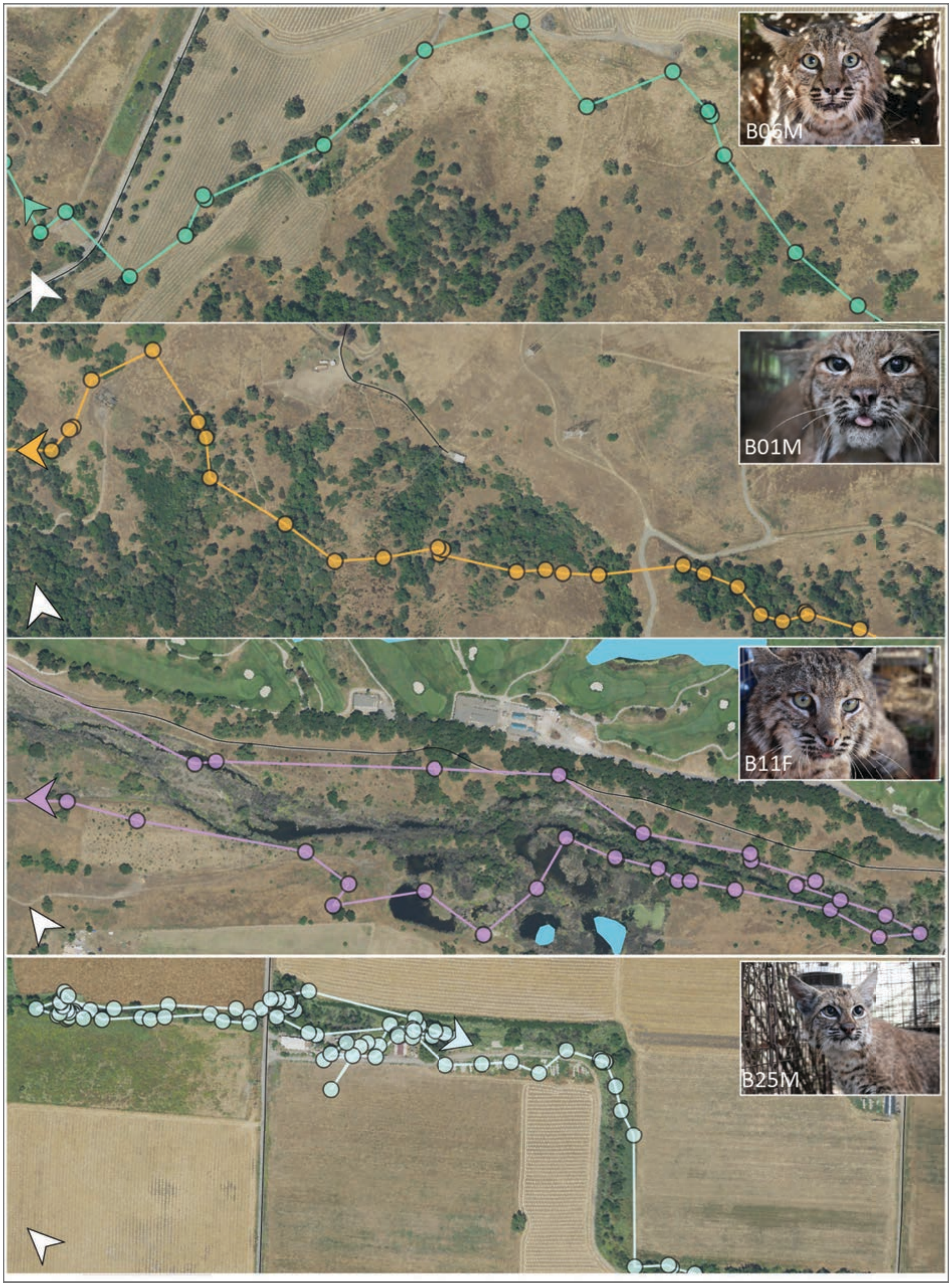

Figure 6. Maps of the GPS-tracking data for three bobcats illustrating the degree to which individuals move from one source of cover (trees or shrubs) to another with successive five-minute movement intervals.

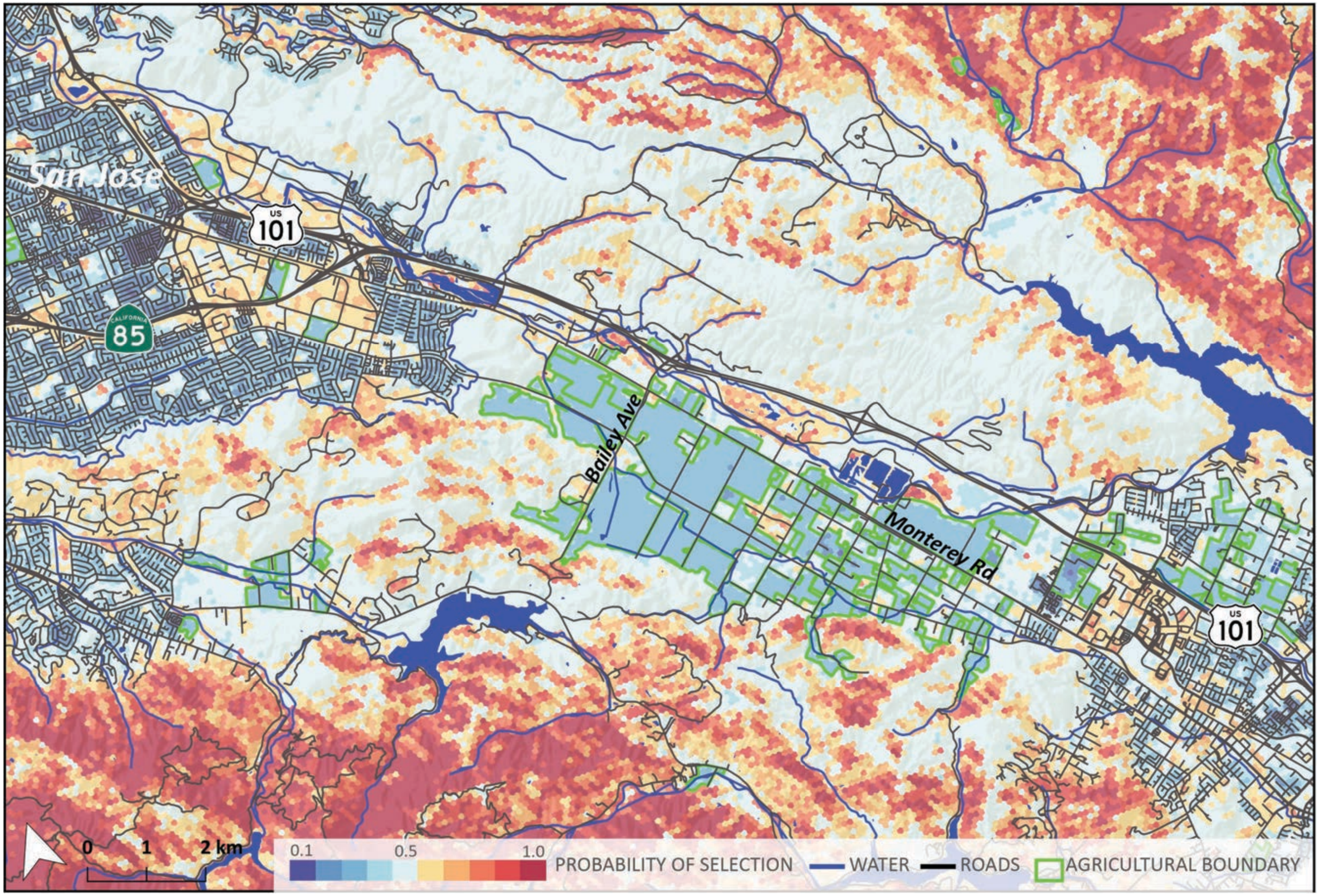

Figure 7. *A map of the probability of selection by bobcats for the entirety of Coyote Valley. The results of our season-independent spatial SSF models were applied to a grid surface of Coyote Valley to predict probability of bobcat selection across the landscape.*

Habitat variable	Seasonal effect	Interpretation
Shrubs	No	Exhibit strongest ***selection for*** shrubs to provide cover as bobcats move across the landscape
Trees	No	Strong ***selection for*** trees, although slightly less than for shrubs, to provide cover as bobcats move across the landscape. Trees offer less cover for bobcats than shrubs.
Row Crops	No	Exhibit strongest ***selection against*** areas with row crops that offer no cover as bobcats move across the landscape.
Orchards	No	***Select against*** orchard areas, but less so than for row crops, likely due to marginal cover offered by tree stands.
Housing density	No	***Select against*** proximity to houses most significantly on the scale of 100-meter distances.
Slope	Yes	***Select for*** steeper areas (likely shaded, cooler drainages) during the hot dry season. No effect during cooler wet season.
Distance from water	Yes	***Selection for*** proximity water during the wet season, likely driven by increased prey availability, not need for water.
Open grassland	No	***Nonsignificant/neutral selection against*** open grassy areas with strong preference shrubs and trees to navigate the landscape. Although nonsignificant, the inclusion of grassy habitat improves model performance, and helps contextualize the importance of trees and shrubs in influencing bobcat movement.
Distance from roads	Yes	***Slight selection for*** proximity to roads during the dry season only. Unclear interpretation but may navigate more along roads (path of least resistance) during the dry season when not navigating closer to water bodies (during the wet season). Additional analyses suggest adults may also "patrol" along roads.

Table 3*. Interpretation of spatial habitat preference model results.*

Road crossings, features of hotspots, and mortalities

We documented 2,875 road crossings within the Coyote Valley floor across six roads of particular importance (Bailey Avenue, Metcalf Road, Monterey Road, Highway 101, Santa Teresa Boulevard, and Bernal Road, Table 4) between June 2017–August 2018 (Tables 4-5, Figures 8-9). Twenty individuals (males, n = 12, females, n = 8) were observed to cross these specific roads of interest while three juvenile individuals did not venture beyond protected areas in Coyote Creek Parkway such that road crossings were required. Eighty-three percent of road crossings were made by adults (17% by juveniles), and 58% were made by females (42% made by males) (Table 5).

There were two roads of particular interest to the study because they were predicted to be important barriers to movement in the Coyote Valley– Highway 101 and Monterey Road. Sixteen percent of documented crossings were across Highway 101, while only 1.8% were documented across Monterey Road (Table 4). Previous camera trap surveys suggested that Route 101 is more permeable to wildlife than Monterey Road (Diamond and Snyder 2016), and these data support that finding. However, all crossings across Highway 101 that were observed for GPS-collared individuals occurred via underpasses comprised of protected, well-vegetated (predominantly riparian) County park land and so this finding is not surprising.

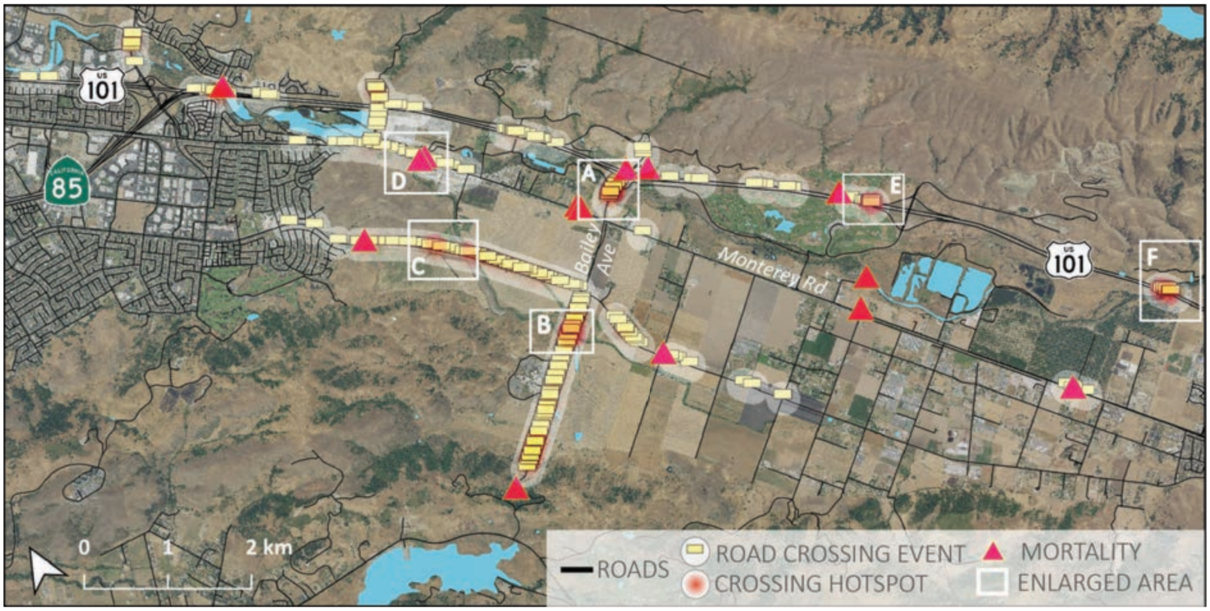

Figure 8. *A map of road crossing locations across all arterial roads of particular interest in Coyote Valley. See Figure 9 for details of enlarged areas.*

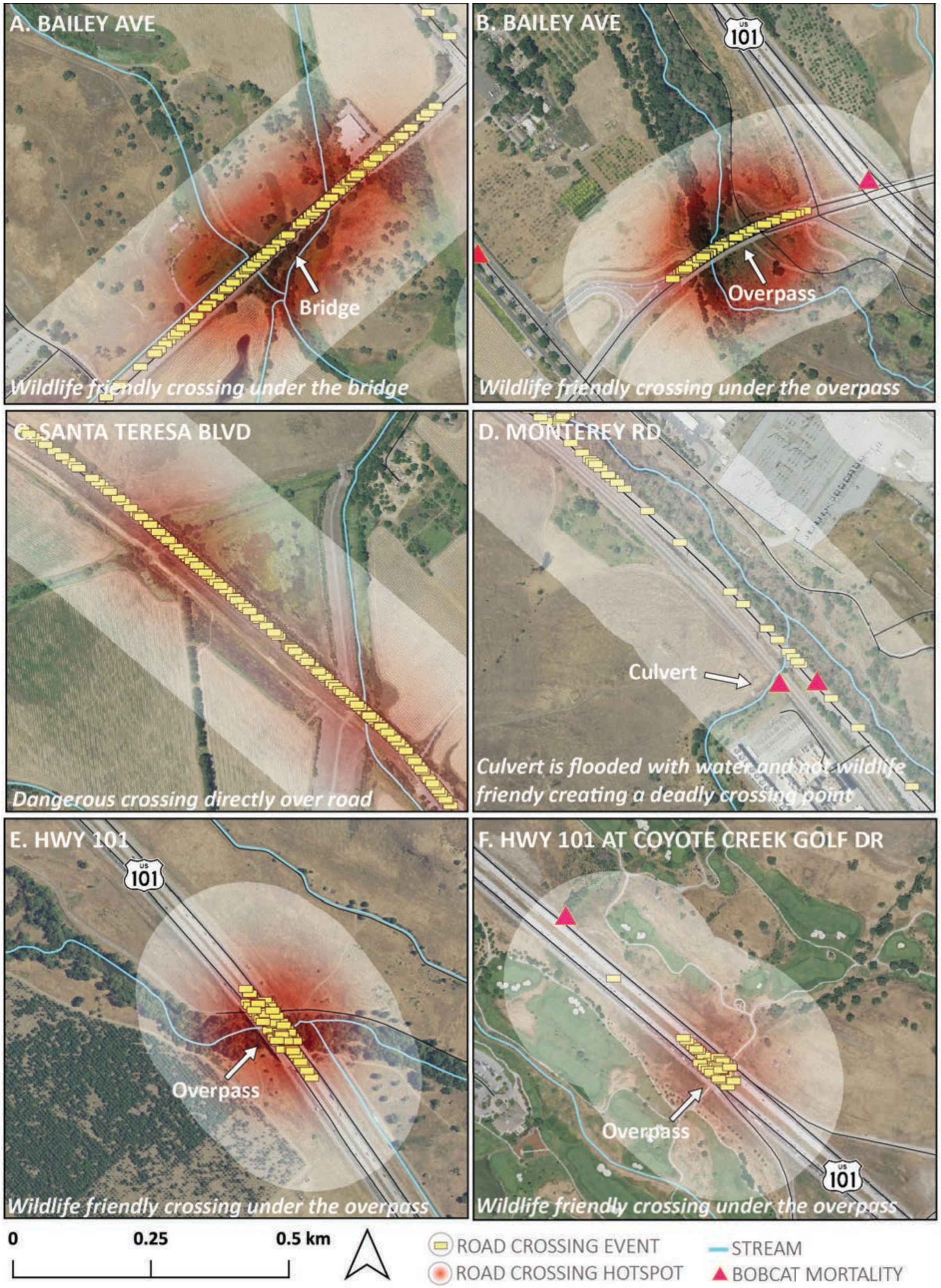

Figure 9. *Enlarged maps of road crossing locations across all arterial roads of particular interest in Coyote Valley. See Figure 8 for location reference.*

Road Name	Number of crossings	Percent of total road crossings	Percent of road mortalities (n = 12)
Bailey Ave	1452	50.5%	0.0%
Metcalf Rd	117	4.1%	0.0%
Monterey Rd	53	1.8%	50.0%
Highway 101	462	16.1%	33.3%
Santa Teresa Blvd	697	24.2%	16.7%
Bernal Rd	94	3.3%	0.0%
Total	2875	100.0%	100.0%

Table 4. *Summary of road crossings made by GPS-collared bobcats stratified by road of interest.*

Bobcat Demographic	Number	Percentage
Female (all)	1657	57.6%
Male (all)	1218	42.4%
Adult (all)	2372	82.5%
Juvenile (all)	503	17.5%
Adult female	1338	46.5%
Adult male	1034	36.0%
Juvenile female	319	11.1%
Juvenile male	184	6.4%

Table 5. *Summary of road crossings stratified by the demographic information of the GPS-collared individuals.*

Figure 10. *Picture of Monterey Road concrete median and wire fencing.*

As predicted, the deadliest, most impermeable, road was Monterey Road. The road offers very few underpasses or culverts and has a concrete median topped with metal fencing that is difficult to see from afar (Serieys, Matsushima, and Basson, personal observations, Figure 10). Nine GPS-collared bobcats crossed Monterey Road, successfully crossing the road 56 times with two (GPS-collared bobcat) unsuccessful crossings (3.6% unsuccessful). Overall, however, 50% of documented vehicle mortalities within the Coyote Valley floor were on Monterey Road. In two case studies (male juvenile bobcats B09M and B26M), we had the opportunity to observe the influence of the median on likely “first-time” crossers. In both cases, the individuals made multiple attempts to cross the road from east to west, only to retreat to the eastern side of Monterey Road once encountering the concrete median for the first time. In the case of B26M, he made multiple crossing attempts with several retreats before successfully crossing one night. He later returned to cross from west to east over Monterey Road and was hit by a car the same evening. In another case study, an adult female (B11F) with somewhat dependent young (B14M, B15M confirmed by genetic assessment), was also hit by a car on Monterrey Road near the same location (i.e., near the Fisher Creek culvert) we observed two previous mortalities. Whether her young survived after her death is unknown, but it is possible that her death had a disproportionate effect on mortality in the population if her young died as well. She was one of two adult females that were hit by cars on Monterey Road, and it is likely that any adults with home ranges straddling Monterey Road are at greater risk for vehicle mortality than for adults with home ranges straddling other wide roads such as Bailey Avenue. Supporting this finding, Monterey Road appears to be an important linear feature that defined the edge of at least two adult home ranges (B01M, B10F) as previously discussed (Figures 2-3). Although Monterey Road is an important barrier to movement, there is little reason to suspect extreme population division and genetic differentiation of bobcats found on either side of the road (see additional information about genetic results below). Our observation of multiple breeding females straddling the Monterey Road, combined with the relative permeability of Highway 101, suggests that there is likely sufficient migration to maintain functional connectivity. However, a more rigorous genetic assessment would be needed to support the telemetry findings. Regardless, numerous wildlife species would benefit from increased permeability of Monterey Road, even if only by removing the metal fencing and center median to facilitate more successful road crossings (see ‘Recommendations’ section below).

Fifty-one percent of road crossings occurred across Bailey Avenue (Table 4, Figures 8, 9A-9B), primarily by adults with home ranges that straddled the road (Figures 2-3). We observed two crossing hotspots across Bailey Avenue (Figures 8, 9A-9B). The crossing spot closest to Highway 101 is a large, well vegetated underpass where animals can safely travel under the busy road without risk of vehicle collision. The crossing hotspot west of Santa Teresa is also well–defined drainage with a small bridge and seasonal water flow. It is unclear the extent to which animals cross over the road as opposed to under at this hotspot, and whether they use the drainage to cross more frequently during the dry season when there is no water in the creek. However, we observed a latrine adjacent to the road at the bridge, suggesting that bobcats sometimes cross over the bridge. We did not document mortalities at this hotspot, however.

Overall, road crossing hotspots shared similar topographical and vegetation features (Figures 8-9). Crossing hotspots were typically lower-lying areas topographically defined by a drainage. Frequently, crossings were also defined by prominent vegetation (trees or shrubs) on either side of the road that offered cover as animals approached the road. Given the bobcats strong selection for shrubs and trees, it is not surprising that these same features define road crossing hotspots. In the case of Highway 101, crossing hotspots were defined by underpasses or culverts in drainages, highlighting the importance regular culvert clearings to promote safe road crossing.

Animal information			Mortality details					Rodenticide compounds detected (ppm)						
Animal	Sex	Age class	Source of mortality	Date	Case type	Latitude	Longitude	Brod.	Brom.	Chlor.	Coum.	Difeth.	Diph.	Total number
B02F	F	A	Vehicle collision	07/01/17	GPS-collared	37.22221	-121.74657	–	–	–	–	–	–	–
B08M	M	A	Domestic dog attack	08/31/17	GPS-collared	37.18902	-121.73248	pos	nd	pos	nd	nd	pos	3
B10F	F	A	Vehicle collision	01/12/18	GPS-collared	37.21779	-121.75853	–	–	–	–	–	–	–
LRM09	M	–	Vehicle collision	01/30/18	opportunistic	37.20881	-121.73136	pos	pos	pos	nd	nd	1.00	4
LRM04	M	A	Vehicle collision	02/13/18	opportunistic	37.19083	-121.73164	pos	pos	pos	nd	nd	pos	4
B11F	F	A	Vehicle collision	02/16/18	GPS-collared	37.22223	-121.74579	–	–	–	–	–	–	–
B04M	M	J	Lethal management	02/16/18	GPS-collared	37.20102	-121.80776	–	–	–	–	–	–	–
LRM05	M	J	Vehicle collision	02/19/18	opportunistic	37.18666	-121.70289	pos	0.14	pos	nd	nd	pos	4
LRM07	M	J	Vehicle collision	03/08/18	opportunistic	37.20924	-121.73157	nd	nd	pos	nd	nd	pos	2
B26M	M	J	Vehicle collision	04/02/18	GPS-collared	37.16505	-121.68658	nd	pos	nd	nd	nd	0.24	2
B25M	M	J	Coyote predation	05/30/18	GPS-collared	37.18042	-121.72747	–	–	–	–	–	–	–
B20F	F	A	Predation by unknown species	06/02/18	GPS-collared	37.19134	-121.70889	–	–	–	–	–	–	–
LRM12	M	A	Vehicle collision	09/16/18	opportunistic	37.18651	-121.75800	0.08	0.99	pos	nd	pos	0.16	5
LRM13	M	–	Mange	09/25/18	opportunistic	36.80165	-121.49746	nd	1.70	0.10	nd	pos	pos	4
LRM16	–	J	–	12/18/18	opportunistic	36.87827	-121.59529	nd	nd	nd	nd	nd	pos	1
LRM03	M	J	Vehicle collision	12/31/18	opportunistic	37.19601	-121.70023	pos	nd	pos	nd	nd	0.11	3

Table 6. *Summary of mortalities documented between 2017-2018. When possible, we collected liver samples during necropsy to test for anticoagulant rodenticide compounds brodifacoum (brod.), bromadiolone (brom.), chlorophacinone (chlor.), coumachlor (coum.), difethialone (difeth.), diphacinone (diph.), warfarin and difenacoum. However, neither warfarin nor difenacoum were detected. A dash (–) indicates where information or samples were unavailable. 'nd' indicates when an anticoagulant compound was not detected. 'pos' indicates when the compound was detected but at the threshold of detection, but too low in concentration to quantify.*

Mortality and rat poisons

We documented 16 bobcat mortalities (GPS-collared, n = 8; opportunistic, n = 8; see map of road mortalities, Figures 8-9, Table 6) between 2017–2018. Previous work by Pathways For Wildlife (Diamond and Snyder 2016) documented an additional four bobcat road mortalities between 2006-2014 that are included in Figures 7-8, but no demographic information was collected and so they are not included in Table 6. For the 16 mortalities that we documented, 63% of mortalities were attributed to vehicle collision (n = 10). We also documented death due to notoedric mange associated with rodenticide exposure (n = 1), predation by coyote (n = 1), domestic dog attack (n = 1), the injury and eventual death of a denning female (n = 1) by an unknown species (suspected coyote), and a permitted depredation (n = 1). In one opportunistic case, the state of decomposition was too advanced to pinpoint cause of death (Table 6).

Mortality surveys can be skewed by detection bias, depending on the approach taken. For example, in the case of opportunistic mortality surveys, roadkill is easier to detect than animals that die away from roads as a result of predation, disease, or poisoning. The deaths of GPS-collared individuals provide the opportunity for an unbiased mortality survey, however, as the GPS collars allowed us to detect mortalities away from roads. For the eight GPS-collared bobcats, 50% (n = 4) were attributed to vehicle collisions, suggesting that even with an unbiased survey, roads are likely the current dominant source of bobcat mortality in the Coyote Valley. The period of study was short, however, and with more effort, other dominant sources of mortality may emerge.

The observation of multiple notoedric mange (*Notoedres cati*) cases (n = 1 opportunistic mortality and B07M developed mange, Figure 11) is troubling. Mange was attributed to a precipitous population declines in multiple southern California study areas (Riley et al. 2006, Delaney et al. 2010, Riley et al. 2014c, Serieys et al. 2015b). In the Los Angeles area where bobcats have been monitored via telemetry since 1996, vehicle collision was the primary source of mortality between 1996–2002. However, mange emerged in the population in 2002 and within three years caused a population decline by an estimated 90% (Riley et al. 2007, 2010, Serieys et al. 2013, 2015a, 2018). The population decline was sufficiently substantial to cause a genetic bottleneck (Serieys et al. 2015b).

The frequency of bobcat mange mortalities in the Los Angeles region is observed to wax and wane, suggesting a degree of complexity to the factors that contribute to high mortality due to notoedric mange. It is worth noting that despite popular misconception, the mange observed in coyotes are typically a different species of mite (*Sarcoptes scabiei).* Experts on notoedric mange dynamics in bobcats do not believe the same dynamics of sarcoptic mange and anticoagulant exposure exists in coyotes (L.E.K. Serieys, S.P.D. Riley, J.E.Foley, personal communication). Rather, the vulnerability of canids to death due directly to anticoagulant rodenticides (see 'Concluding remarks') can make rodenticide exposure itself a leading source of mortality for coyotes (Gehrt et al., 2010). However, extensive research has focused on a relationship between exposure to anticoagulant rodenticides (rat poisons) and notoedric mange in bobcats (Riley et al. 2007, 2010, Serieys et al. 2013, 2015a, 2018, Fraser et al. 2018). For example, bobcats that were exposed to multiple anticoagulant compounds were seven times more likely to die of notoedric mange than any other source of mortality (Serieys et al. 2015a). More recently, researchers have linked anticoagulant exposure with multiple sublethal consequences including immune dysfunction and interference with wound healing ability of the skin. These sublethal consequences explain increased susceptibility to notoedric mange in bobcats (Fraser et al. 2018, Serieys et al. 2018)

Figure 11. *Pictures of B07M after he was captured healthy in July 2017, and with severe notoedric mange in February 2018.*

Within Coyote Valley, we tested the liver of ten bobcats for the presence and amount of eight different anticoagulant rodenticide (AR) compounds. We detected AR exposure in all individuals tested, resulting in 100% exposure. We detected six different compounds across the individuals, with an average of three different compounds detected in the bobcats (range: 1-5 compounds, Table 6). The detection of multiple compounds indicates multiple exposure events, and potentially chronic exposure, because baits are formulated with single compounds. The average concentration of compounds detected in individuals was 0.45 ppm (sd = 0.65, range: <0.05–1.8 ppm), which is similar to what was detected in a larger study in southern California (Serieys et al. 2015a) despite the 2014 California Department Regulations intended to reduce the ecological risk of anticoagulant rodenticides. Of note, the individual with the highest concentration of poisons was exposed to four different compounds and death was attributed to mange. We detected both second-generation (brodifacoum, bromadiolone, difethialone) and first-generation (diphacinone, chlorophacinone) compounds. Although first-generation compounds are considered ecologically "safer" than second-generation compounds, first-generation anticoagulant exposure is significantly linked with immune dysfunction in bobcats. Further, first-generation compounds are especially common in agricultural areas and thus targeted mitigation in Coyote Valley may include anti-poison campaigns in the agricultural areas.

Population	N	Heterozygosity
Coyote Valley	17	0.726
Golden Gate	12	0.679
Los Angeles	196	0.700
Orange County	124	0.716
San Diego	73	0.755

Table 7. Heterozygosity of six bobcat populations (Smith et al., in review) measured using 11 microsatellite markers. Coyote Valley has amongst the highest heterozygosity, suggesting a high degree of genetic connectivity in the area. Northern California populations are shaded in gray.

Genetics

Genetic variation (as measured by heterozygosity based on genotyping 11 microsatellite loc) for Coyote Valley bobcats was among the highest values in a recent survey of five California populations (Coyote Valley, Golden Gate National Park, Los Angeles, Orange County, and San Diego, Table 7, Smith et al. *in review*). With more extensive analyses between the three southern California populations, San Diego exhibited the greatest genetic connectivity. While similar assessments were not possible with the limited sampling in Coyote Valley and surrounding populations, the genetic variation measured by heterozygosity complimented with the movement of individuals across Highway 101 is reassuring that the population retains a high degree of genetic connectivity with surrounding areas.

CONCLUDING REMARKS

Over the course of this short study, we collected an immensely detailed dataset that is especially informative about the ecology of bobcats in Coyote Valley. However, bobcats were chosen as a species that would be informative about overall landscape connectivity and as a generalist mesocarnivore, they can also indicate the quality of habitat available on the landscape. Bobcats are considered a species "moderately" adaptable to anthropogenic habitat modification (Crooks 2002, Riley et al. 2003, Bateman and Fleming 2012, Poessel et al. 2014). In our initial conceptualization of this study, we planned to also capture and GPS-collar gray foxes in the study given that they are considered even more sensitive to habitat fragmentation than other mesocarnivores such as bobcats, coyotes, and racoons (Crooks 2002, Riley et al. 2003, 2010, Gehrt et al. 2010, Ordeñana et al. 2010, Bateman and Fleming 2012). Gray foxes were documented previously in Coyote Valley (Diamond and Snyder 2016). However, we did not capture any gray foxes during the course of our fieldwork, and we found little evidence of their presence in Coyote Valley currently. While the population of bobcats and other carnivores appears relatively healthy based on our observations and tracking records (i.e., we caught numerous other species as bycatch including racoons, striped skunk, and even coyotes that are rare to trap in cages), the lack of gray foxes on the landscape is troubling and could be linked with their sensitivity to urbanization. We detected rodenticide exposure in bobcats, and canid species can be 100x more susceptible to some anticoagulant compounds compared with cats (Erickson and Urban 2004, Fraser et al. 2018). Coyotes and endangered kit foxes are known to suffer high mortality associated with anticoagulant exposure (Riley et al. 2003, McMillin et al. 2008, Cypher et al. 2014). Alternatively, infectious disease could have led to a precipitous population decline, and gray foxes are noted to be vulnerable to pathogens carried by domestic dogs (Riley et al. 2014b). The spillover of disease maintained in urban adapted hosts or domestic animal species to rarer wildlife species can negatively affect native wildlife and may even lead to dramatic population declines (Riley et al. 2014b). Alternatively, the absence of gray foxes could be linked with factors we are unable to detect with our bobcat work (i.e., competitive exclusion of gray foxes by coyotes). We therefore proceed with management recommendations, and directions of future research based both on the findings of our bobcat study, but also the troubling lack of gray foxes in an area they were recently documented.

MANAGEMENT RECOMMENDATIONS

Based on the findings of this study, we make the following management recommendations:

- **Habitat restoration.** Native vegetation that provides cover will be instrumental in facilitating wildlife movement between the Santa Cruz Mountains and the Diablo Range. It also provides shelter and resting areas for numerous species, including bobcats and their prey (e.g., small rodents and hares). We recommend restoring both faster growing native shrubs so as to provide immediate cover as well as slower growing native trees to provide long term cover in heavily impacted parcels, especially adjacent to Fisher Creek (e.g. as in Figure 6, Panel B25M), and parcels intersecting major roads where culverts or underpasses already exist.

- **Repair culverts and underpasses to ensure “wildlife friendly” road-crossing locations.** Where there are already culverts that are feasible for wildlife use across major roads, ensure they remain clear of debris and passable by wildlife. In particular, we also recommend retrofitting the Fisher Creek culvert under Monterey Road to remove standing water and increase suitability for wildlife use.
- **Funnel wildlife to safe road-crossing points**. Fencing installed along roads, coupled with restored vegetation, and retrofitted or maintained culverts, can guide wildlife to safe crossing points and prevent indiscriminate crossing attempts, particularly on dangerous roads such as Monterey Road and Highway 101.
- **Add under or over passes to Monterey road while simultaneously restoring more habitat along Monterey road.** Monterey road is currently a pinch point for animals trying to get from one side of the valley to the other. The only viable crossing is at Fisher Creek. To ensure the long-term value of the Coyote Valley for wildlife connectivity, their needs to be more viable crossings. This could be achieved by protecting and restoring habitat south of Fisher creek and adding more crossing structures to Monterey road.
- **Reduce risk of collisions on Monterey Road.** We recommend removing the metal fencing atop the concrete median, and also remove or reduce the concrete median, that bisects Monterey Road.
- **Outreach campaigns that reduce rodenticide use.** Rodenticides kill wildlife across California, including bobcats, coyotes, gray foxes, mountain lions, and numerous avian predators. They are particularly common in agricultural and residential areas. Targeted “break the poison chain” campaigns could reduce the pervasiveness of the compounds on the landscape

FUTURE DIRECTIONS

- **Future research: a robust genetic survey**. Conduct a robust study investigating potential genetic segregation of populations separated by Monterey Road and Highway 101. Carnivore species that exist in low-density populations (such as bobcats) are excellent indicator species of genetic processes on the landscape. We recommend opportunistic sample collection from roadkill or other mortalities, targeting a sample size of approximately 20 individuals sampled on either side of Highway 101 and/or Monterey Road. Because samples were already collected from nearly 30 bobcats as part of this study, they are an excellent candidate for deeper genetic investigations. However, a multi-species study would provide added insight.
- **Future research: gray foxes.** This study was initially conceptualized to include gray fox habitat preference and movement ecology, but we were unable to detect foxes once trapping commenced. The apparent absence of gray foxes when they were recently present may be linked with infectious disease, rodenticides, poor habitat quality, or competitive exclusion by coyotes. Noninvasive surveys aimed at collecting fox-specific data may help pinpoint the cause of the apparent decline in Coyote Valley foxes. For example, pathogen testing on fecal samples opportunistically collected could reveal infectious disease dynamics that may have precipitated a population decline. Further, preliminary testing of bobcat samples collected in the Coyote Valley suggest a high prevalence of canine parvovirus in bobcats. In the absence of sample collection from gray foxes themselves, scat surveys aimed at carnivores that are also vulnerable to canine pathogens may yield insights as to the pervasiveness of disease across the landscape.

APPENDIX A. DETAILED METHODS

Ethical Statement

All animal capture, handling, collaring, and sample collection was approved by the Institutional Animal Care and Use Committee (IACUC) of University of California, Santa Crus (Protocol Seril1701 and Seril1701_a1). Scientific collecting permits were authorized by the California Department of Fish and Wildlife (SCP-13565).

Trapping, sample collection, and opportunistic mortalities

We trapped bobcats during the dry (May 15 – July 30, 2017) and wet (November 1, 2017–January 15, 2018) seasons using standardized cage-trapping techniques (Serieys et al. 2013). Briefly, we used cage traps (Tru–catch traps, Bell Fourche, South Dakota or CamTrip cages, Caging Bobcats, Barstow, California) that were baited with a variety of visual, audio, and scent lures. Traps were check a minimum of every 12-hours.

Once captured, individuals were chemically immobilized with a mixture of ketamine HCl (5 mg/kg) and medetomidine HCl (0.1 mg/kg) as in Serieys et al. (2013). We recorded age class, sex, weight, and morphological measurements (i.e., chest circumference, body length, tail length, ear length, head circumference, etc.). Individuals were classified as juveniles (<2 years) or adults (≥2 years) based on body size, weight, tooth wear and eruption, and reproductive status (Serieys et al. 2015a). All individuals were collared using GPS and triaxial accelerometers (Eobs GmbH; Grünwald, Germany) that collected GPS locations at 5-minute intervals when the animal was moving, and at 3-hour intervals when the animal was at rest. To ensure GPS-collars were less than 3% of animal weight, as is recommended by the American Society of Mammologists, we used collars fit with either 1C or 1A batteries. All GPS-collars were also fit with rot-off cotton spacers inserted directly into the collar belting. These spacers were intended to decay, thus allowing the collars to fall off without recapture and animal handling. We prepared cotton spacers with the intention that they decayed between three months to one year, depending on the age (and expected growth) of the individual collared.

We collected a variety of samples for genetic, pathogen, and microbiome assessment. Whole blood was collected via cephalic or saphenous venipuncture. To obtain serum samples, blood was centrifuged within 24 h of collection. We preserved 1 ml of whole blood in PAXgene blood RNA buffer (Qiagen, Venlo, Netherlands), fecal samples, and urine via cystocentesis when possible. Three microbiome swab samples were collected from all radio-collared individuals: i) dermal, ii) fecal, and iii) buccal. Microbiome samples were collected as a first step at captures to prevent contamination of samples by animal handling protocols. Microbiome samples were preserved in RNA*later*® (Sigma-Aldrich, St. Louis, Missouri) and were shipped to the American Museum of Natural History for sequencing by collaborators as part of a larger felid microbiome survey (Ingala et al. 2018). Finally, we collected a fecal swab preserved in Universal viral transport media (Becton Dickinson, East Rutherford, New Jersey) to test for a variety of viral pathogens novel to felid and canid carnivores. These samples were shipped to the Arizona State University Biodesign Institute where they are being processed by collaborators (A. Varsani and S. Kraberger) to test for novel viruses (e.g., Kraberger et al. 2019) and parvoviruses. All samples were transported from the site of collection to storage facilities on ice packs. Samples are available for pathogen, genetic, and health assessment and are in storage -80^{o}C storage at University of California, Santa Cruz, until tested.

Counting Road Crossings

We used 5-minute relocation data (496,104 GPS collar locations) to identify the date, time, and coordinates of road-crossing events for each individual. We focused this analysis only on major arterial roads of particular interest in the CV study area, namely Monterey Road, Highway 101, Bailey Avenue, Santa Teresa Boulevard, and Bernal Road. Road crossing counts and geometry (start, end, and mid-point coordinates) were performed using package *sf* (Pebesma 2018) in R (R Core Team, 2014). We summarize mean crossing events per individual, age class, and sex. We visualized road crossing hotspots using a kernel density estimation heatmap of crossing events in using the 'Heatmap' plugin in QGIS (QGIS Development Team, 2018).

Landscape Variables

To assess the role that vegetation patches influence bobcat movement across the landscape, we created a high-resolution GIS layer that mapped all trees and shrubs in the study area. To create the layer, we first used a supervised image classification using maximum-likelihood in ArcMap 10.1 that classified all pixels into one of five classes: (1) TREES, (2) SHRUBS, (3) Open GRASSLAND areas, (4) Concrete/Rock, (5) Water. We acquired remote sensing imagery in four bands (blue, green, red, near infrared) from the United States Department of Agriculture (USDA) 2016 National Agricultural Imagery Program (NAIP; www.fsa.usda.gov/programs-and-services/aerial-photography/imagery-programs/naip-imagery/) sampled at 0.6 m resolution (USDA NAIP). We applied a two-pixel by two-pixel filter to remove errant pixels in R, resulting in 1.2 meter resolution imagery. We subsequently used the California Department of Conservation agricultural layer for Santa Clara County (California Department of Conservation; consrv.ca.gov) to reclassify pixels as (6) Agriculture. Informal quality assessment revealed shaded vegetation classified as water; we corrected for this by masking out water bodies using the USGS Natural Hydrography Dataset (NHDH_CA_92v200; www.usgs.gov) water layer and reclassifying remaining pixels (initially classified as water) as TREES (class 1).

We reprojected used and available bobcat locations from WGS84 into NAD UTM Zone 10N coordinate reference system and sampled vegetation (TREES, SHRUBS, GRASSLAND) at each location. Location accuracy of the GPS collars was greater than the resolution of the vegetation classification. To account for the possibility that locations recorded outside natural vegetation might reflect error in location measurements, we assigned the nearest natural vegetation class (1: TREES or 2: SHRUBS) within 5 meters.

For each used and available location, we estimated landscape features including distance from the nearest water body (WATER DISTANCE: streams, ponds, or lakes; USGS Natural Hydrography Dataset [NHDH_CA_92v200]; www.usgs.gov), elevation and slope (SLOPE) extracted from the California Digital Elevation Model (ELEVATION, 90 m resolution; 2010 ESRI), and whether GPS locations were located within five meters of a tree (TREES) or shrub (SHRUBS) (see above). We also calculated the distance of each location from the nearest arterial road (ROAD DISTANCE; ESRI Roads [DataMaps10.2]), whether points were located in agricultural areas that included orchards and row crops (ORCHARDS or CROPS, California Department of Conservation; consrv.ca.gov;), and the housing density within a 100-meter buffer surrounding each location (HOUSING DENSITY, based on Microsoft's Building Footprints; Open Data Commons Database License).

Movement-specific habitat selection

We identified the key landscape features that inform bobcat movement within Coyote Valley using step selection function (SSF) analyses (Thurfjell et al. 2014). In preparation to perform these analyses, we filtered 5-minute to 3-hour translocations (*t*) to reduce the effects of autocorrelation and to correct for potential GPS error in locations. We calculated relative turn angles and step length (distance between consecutive GPS locations, Figure A1) using *adehabitatLT* (Calenge 2006, 2007, Calenge et al. 2009). We created a match-case control design whereby each 3-hour GPS location 'used' (*t*) by an individual was matched with 20 random 'available' locations (Fortin et al. 2005, Wilmers et al. 2013, Suraci et al. 2019). Available locations represented locations on the landscape that bobcats could have visited instead of the documented used location (*t*).

The match-case control design defines available habitat as that which could be used based on the distribution of step lengths (distance between consecutive 3-hour translocations). Therefore, when generating the collection of available locations per used location, we created random vectors originating from the location immediately preceding used location *t* (i.e., location *t*-1; (Thurfjell et al. 2014, Blecha et al. 2018, Suraci et al. 2019). To draw each vector, we sampled (with replacement) from a distribution of step lengths and relative turn angles calculated between consecutive three-hour locations across all individuals that were the same sex as the focal individual. However, we excluded the focal individual's step and turn angle data from the sampling distribution to avoid circularity (Fortin et al. 2005). All available locations were assigned the same date, time, and animal ID as their matched used location. We also calculated STEP length between *t* and *t*-1, and the relative DIRECTIONAL PERSISTANCE of the individual (a measure of how "straight" the animal travelled) between *t*, *t*-1, and *t*-2. STEP, log-transformed STEP (LOG[STEP]), and DIRECTIONAL PERSISTANCE were included in all models to control for inherent movement behaviors (i.e., ability to move certain distances within 3-hour intervals and the natural bias of animals to move in a consistent directional pattern, Suraci et al. 2019).

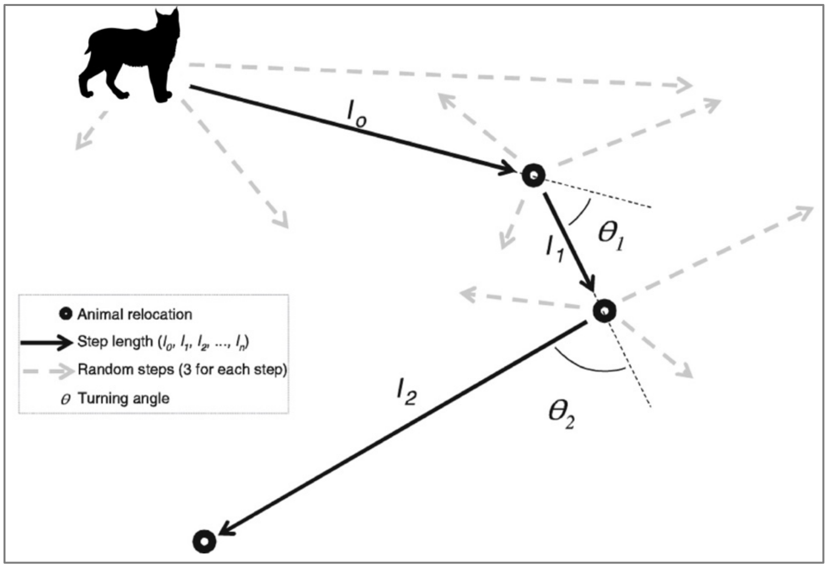

Figure A1. *Illustration of the principal of Step Selection Functions and the process of generating random 'available' locations that are matched with each 'used' location. Adapted from Thurfjell et al. 2014.*

To fit SSF models, we performed analyses on the entire dataset (all individuals including males, females, juveniles and adults) across both seasons to first calculate an overall model of the relative influence of landscape features driving bobcat movement. Afterwards, we performed analyses on wet and dry season data separately to test for seasonal differences in bobcat movement across Coyote Valley. We calculated SSF (ß) coefficients using conditional logistic regression (CLR) using the coxph function in the *survival* package in R (Therneau 2018). We also calculated robust standard errors for all model coefficients using generalized estimating equations (GEE) (Koper and Manseau 2009; Prima et al 2017). For GEE analysis, to control for autocorrelation in movement data, we created independent data clusters with one cluster per individual, with the exception of two females that were recollared. In these cases, they were split into two clusters corresponding with the two collaring intervals. In total, we had 26 clusters following recommendations of Prima et al. (2017) to use between 20-30 clusters to optimize model performance .

Each categorical variable was converted to binary covariates (TREES, SHRUBS, GRASS, ORCHARDS, CROPS). All covariates (continuous and categorical) were standardized to mean = 0 and standard deviation = 2 (Gelmen and Hill 2007). We tested for collinearity between covariates using Pearson correlations, and found that ROAD DISTANCE and ELEVATION were strongly correlated ($r > 0.7$). We therefore eliminated ELEVATION from our models since the effect of roads was a primary interest of the study. After eliminating elevation as a covariate, all $|r| \leq 0.47$.

We fit models consisting of every combination of covariates sampled, and compared all using the quasi-likelihood under independence criterion (QIC) as suggested by Craiu et al. (2008). The models reported were the results of the top model as determined by QIC selection. We report the selection coefficient ß, exponentiated ß, standard errors, robust standard errors, p-value, and 95% confidence intervals calculated using the robust standard errors.

With respect to choosing the scale at which housing density exerted the most influence on bobcat habitat selection, we calculated housing density individually at scales of 50 meters– 1000 meters radius surrounding each 'used' and 'available' location, using 50 -100 meter increments. We tested the relative effects of these of at 16 different scales using a univariate approach that controlled for directional persistence and step length. We calculated the selection coefficient ß, exponentiated ß, standard errors, robust standard errors, p-value, and 95% confidence intervals calculated using the robust standard errors and QIC. We selected the scale based on QIC, and found that a radius of 100-meter measure of housing density exerted the strongest influence on bobcat movement

Home-range estimates

For adult individuals that were radio-collared for a minimum of 30 days, we calculated 95% kernel-density estimates (KDE), one of the most commonly used techniques for estimating home range size (Kie et al. 2010, Walter et al. 2011). To calculate KDE, we used the package *adehabitatHR* (Calenge, 2015) in R (R Development Core Team, 2014).

Contributors to mortality

We performed mortality surveys for GPS-collared individuals on a weekly-monthly basis, depending on the ease of location of the individual and the timing of fieldwork. If GPS-collared bobcats died, we collected their carcasses for necropsy. We opportunistically collected bobcat carcasses in Coyote Valley, primarily killed as a result of vehicle collisions. Carcasses were either necropsied immediately upon retrieval or stored at -20^{o}C until necropsies could be performed. The cause of mortality, collection date, sex, age class, and GPS location of each carcass was recorded when possible.

Consistent with other studies in California (Riley et al. 2007, 2010, Gehrt et al. 2010, Gabriel et al. 2012, 2018, Serieys et al. 2013, Cypher et al. 2014, Serieys et al. 2015a), we tested for the presence and quantity of anticoagulant rodenticides (ARs) in the liver of animals that died in the study area when feasible. The detection of these compounds in liver reflects the history of exposure for the individual and is therefore the preferred tissue for AR studies (Serieys et al. 2015a). We removed (a portion of) the liver from each carcass and stored all liver and serum samples at -20^{o}C. AR compounds are stable and so the length of storage time does not affect compound detection results (Waddell et al. 2013). We later assessed the presence and concentrations of eight anticoagulant compounds in 2 g of liver tissue at the Center for Health and Food Safety at University of California, Davis. Samples were first screened for AR compounds using liquid chromatography-mass spectrometry (LC–MS/MS). If ARs were detected, then amounts were quantitated using high-performance liquid chromatography (HPLC). The approach is standardized and previously described (Serieys et al. 2015a) . The compounds tested were a standard panel of commercially available compounds that included first-generation compounds (warfarin, coumachlor, chlorophacinone, and diphacinone) and second-generation rodenticides (bromadiolone, brodifacoum, difethialone and difenacoum). Limits of quantitation for these anticoagulants in wet liver tissue were 0.01 ppm for brodifacoum, 0.05 ppm for bromadiolone, warfarin, and coumachlor, and 0.25 ppm for chlorophacinone, diphacinone, and difethialone.

Genetics

We contributed 17 Coyote Valley bobcat samples to a southern California regional scale landscape genetics project (Smith et al., in review). Two northern California study areas were included for contextualization of genetic differences measured between populations with various distances and degree of separation by urbanization between them. Coyote Valley and Golden Gate National Park comprised the two northern California outgroups. Individuals were genotyped at 11 microsatellite loci and heterozygosity was measured for all populations as a proxy for genetic connectivity of the populations.

APPENDIX B. SUPPLEMENTARY TABLES

ID	Sex	Age Class	Start Date	End Date	Days Collared	Total number GPS points	Number 3- hour locations	Fate	Capture Latitude	Capture Longitude	Mortality Latitude	Mortality Longitude
B01M	M	A	06/03/17	01/26/18	237	50772	1527	Collar battery died	37.21476	-121.74728	NA	NA
B02F	F	A	06/21/17	07/01/17	10	8486	83	Dead (Hit by car)	37.22380	-121.75130	37.22221	-121.74657
B03F	F	A	07/02/17	08/22/18	416	44194	2788	Collar battery died	37.19020	-121.75640	NA	NA
B04M	M	J	07/02/17	02/16/18	229	33170	1468	Dead (Lethal management)	37.19590	-121.76520	37.20102	-121.80776
B05F	F	A	07/05/17	07/09/18	369	53594	2348	Collar battery died	37.19742	-121.74253	NA	NA
B06M	M	A	07/08/17	03/26/18	261	30129	1652	Collar battery died	37.19020	-121.75640	NA	NA
B07M	M	A	07/14/17	02/25/18	226	22452	1290	Unknown (Mange)	37.16891	-121.66828	NA	NA
B08M	M	A	07/15/17	08/31/17	47	6496	321	Dead (Domestic dog attack)	37.16850	-121.72770	37.18902	-121.73248
B09M	M	J	11/18/17	02/27/18	101	11583	399	Collar fell off	37.16891	-121.66828	NA	NA
B10F	F	A	11/20/17	01/12/18	53	4852	196	Dead (Hit by car)	37.21476	-121.74728	37.21779	-121.75853
B11F	F	A	11/21/17	02/07/18	78	11237	422	Dead (Hit by car)	37.16880	-121.66780	37.22223	-121.74579
B12M	M	J	11/22/17	01/27/18	66	7601	276	Collar fell off	37.20300	121.71785	NA	NA
B13M	M	J	11/23/17	02/26/18	95	11117	424	Collar fell off	37.20300	121.71785	NA	NA
B14M	M	J	12/06/17	12/24/17	18	2736	103	Collar fell off	37.21394	-121.72817	NA	NA
B15M	M	J	12/07/17	03/11/18	94	12330	450	Collar fell off	37.21394	-121.72817	NA	NA
B16M	M	J	12/09/17	03/19/18	100	13445	488	Unknown (Lost track of cat)	37.19094	-121.70623	NA	NA
B17F	F	J	12/09/17	07/11/18	214	31303	1469	Unknown (Lost track of cat)	37.19094	-121.70623	NA	NA
B18F	F	J	12/14/17	05/02/18	139	18389	810	Collar battery died	37.18702	-121.73036	NA	NA
B19F	F	J	12/15/17	07/10/18	207	22906	1318	Collar battery died	37.18095	-121.69487	NA	NA
B20F	F	A	12/16/17	06/02/18	168	22893	1032	Died (Unknown injury - predation)	37.19094	-121.70623	37.19134	-121.70889
B21M	M	J	12/18/17	12/20/17	2	262	NA	Collar fell off prematurely	37.16780	-121.65380	NA	NA
B22M	M	A	12/20/17	08/01/18	224	31032	1438	Collar battery died	37.23198	-121.74536	NA	NA
B23M	M	A	01/09/18	07/16/18	188	25185	1282	Collar battery died	37.21394	-121.72817	NA	NA
B24F	F	J	01/15/18	01/20/18	5	928	30	Collar failed	37.18239	-121.72949	NA	NA
B25M	M	J	01/16/18	05/30/18	134	14585	854	Died (Coyote predation)	37.18702	-121.73036	37.18042	-121.72747
B26M	M	J	02/26/18	04/02/18	35	4427	221	Dead (Hit by car)	37.16458	-121.66922	37.16505	-121.68658

Table B1. *Demographics and fate of bobcats captured and monitored in the Coyote Valley.*

Covariate	ß estimate	exp(ß estimate)	SE	Robust SE	*p*-value	Lower 95% CI	Upper 95% CI
Shrubs	1.12	3.07	0.03	0.19	**< 0.0001**	0.75	1.49
Trees	1.02	2.77	0.02	0.11	**< 0.0001**	0.80	1.24
Row Crop	-0.70	0.50	0.03	0.07	**< 0.0001**	-0.83	-0.56
Distance from water	-0.87	0.42	0.03	0.30	**0.004**	-1.46	-0.28
Housing density	-0.30	0.74	0.03	0.05	**< 0.0001**	-0.40	-0.21
Open grassland	-0.26	0.77	0.03	0.18	0.150	-0.62	0.09
Orchard	-0.18	0.84	0.02	0.03	**< 0.0001**	-0.24	-0.11
Directional persistence	0.06	1.07	0.02	0.06	0.275	-0.05	0.18
Step length	-0.12	0.89	0.03	0.22	0.580	-0.55	0.31
Log(Step length)	0.56	1.74	0.03	0.12	< 0.0001	0.32	0.79

Table B2. *Results from the top habitat selection for the wet season. A positive selection coefficient (ß) generally indicates a positive association between selection and the covariate. However, a negative value for WATER DISTANCE indicates a positive association. Habitat covariates that were significant are in bold. Upper and lower 95% confidence intervals were calculated using the robust standard error (SE). Where confidence intervals cross zero, the parameter is not significant, but it may still be included in the top model. The presence of DIRECTIONAL PERSISTENCE, STEP, and LOG(STEP) correct for the effect of inherent behavioral constraints. Animals tend to move in straight trajectories (DIRECTIONAL PERSISTENCE), whereas STEP and LOG(STEP) control for the ability of an animal to move certain distances within the given time frame and that the strength of their selection may change relative to their distance from various landscape features.*

Covariate	ß estimate	exp(ß estimate)	SE	Robust SE	*p*-value	Lower 95% CI	Upper 95% CI
Shrubs	1.18	3.25	0.04	0.18	**< 0.0001**	0.83	1.53
Trees	1.03	2.81	0.03	0.12	**< 0.0001**	0.80	1.27
Row Crop	-0.58	0.56	0.03	0.09	**< 0.0001**	-0.76	-0.40
Distance from water	-0.30	0.74	0.03	0.23	0.194	-0.74	0.15
Housing density	-0.23	0.79	0.04	0.04	**< 0.0001**	-0.31	-0.16
Open grassland	-0.13	0.88	0.04	0.16	0.405	-0.44	0.18
Orchard	-0.26	0.77	0.04	0.02	**< 0.0001**	-0.29	-0.22
Slope	0.26	1.29	0.03	0.10	**0.010**	0.06	0.45
Distance from roads	-0.45	0.64	0.04	0.24	0.059	-0.91	0.02
Directional persistence	0.29	1.34	0.02	0.08	< 0.0001	0.14	0.44
Step length	0.10	1.10	0.03	0.30	0.738	-0.48	0.68
Log(Step length)	0.24	1.27	0.03	0.22	0.278	-0.19	0.66

Table B3. *Results from the top habitat selection for the dry season. A positive selection coefficient (ß) generally indicates a positive association between selection and the covariate. However, a negative value for WATER DISTANCE indicates a positive association. Habitat covariates that were significant are in bold. Upper and lower 95% confidence intervals were calculated using the robust standard error (SE). Where confidence intervals cross zero, the parameter is not significant, but it may still be included in the top model. The presence of DIRECTIONAL PERSISTENCE, STEP, and LOG(STEP) correct for the effect of inherent behavioral constraints. Animals tend to move in straight trajectories (DIRECTIONAL PERSISTENCE), whereas STEP and LOG(STEP) control for the ability of an animal to move certain distances within the given time frame and that the strength of their selection may change relative to their distance from various landscape features.*

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