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Evaluating Wildlife Corridor Linkages: Do Freeway Underpasses Connect the Peninsular and Transverse Mountain Ranges?

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Publication Date
2011

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UNIVERSITY OF CALIFORNIA
RIVERSIDE

Evaluating Wildlife Corridor Linkages: Do Freeway Underpasses Connect the Peninsular
and Transverse Mountain Ranges?

A Thesis submitted in partial satisfaction
of the requirements for the degree of

Master of Science

in

Evolution, Ecology, and Organismal Biology

by

Michelle L. Murphy

December 2011

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Acknowledgments

I'd like to convey my sincere gratitude to my advisor, Michael Allen, who has invested much of his time and attention to exposing me to new ecological experiences and ideas, which have shaped me into a better researcher. I am also deeply appreciative to Cameron Barrows, who opened my eyes to the wonders of our Southern Californian desert, who taught me the wildlife tracking skills I utilized for this project, and who has inspired immeasurably. This project would not have been possible without both of their support and guidance. I would also like to thank my committee members, John Rotenberry and Richard Redak, for making themselves available to me when I needed direction, as well as for their thoughtful feedback on this manuscript and its earlier versions.

Special thanks go to the staff at the Center for Conservation Biology, namely Veronique Rorive and Cecelia Gonzalez, for their administrative assistance, Robert Johnson, for his GIS expertise, and Kuni Kitajima, for his statistical knowledge. Katie O'Connor, from The Friends of the Desert Mountains, assisted me in securing permits from landowners and was immensely helpful throughout the course of the project.

I would like to thank the individuals who served as my assistants in the field: Michele Felix, Carlos Mariscal, Tim Mok, and Jung Hur. I could not have asked for a

more enthusiastic and motivated group of students, and I am very grateful for their tireless work and effort on this project.

Finally, I would like to thank my support system at home. My parents, Peter and Debra Murphy, who inspired my love for nature at a young age and who continually nurtured that passion with camping trips and excursions to national parks; and my fiancé, Carlos Mariscal, who has been my biggest fan, source of encouragement, and hardest working field assistant during this project. These three people realized my potential before even I did, and I am extremely grateful for their love and support.

ABSTRACT OF THE THESIS

Evaluating Wildlife Corridor Linkages: Do Freeway Underpasses Connect the Peninsular
and Transverse Mountain Ranges?

by

Michelle L. Murphy

Master of Science, Graduate Program in Evolution, Ecology and Organismal Biology
University of California, Riverside, December 2011
Dr. Michael F. Allen, Chairperson

Habitat connectivity is a key component for the persistence of populations, for

maintaining genetic diversity, and for weathering environmental extremes and climate

shifts. Desert environments are stressful largely because of extreme swings in

precipitation and temperature, and thus maintaining connectivity becomes a critical

conservation strategy to ensure mobile species can track temporal and spatial shifts in

habitat suitability. These linkages are especially critical in light of expected distributional

shifts due to climate change. Expansion of urbanization and energy resource

development, as well as the transportation and energy infrastructure required to support

those changes, are fragmenting desert environments at an increasing rate. Highway

underpasses and culverts are often identified in conservation planning as wildlife

corridors, providing connections between previously contiguous suitable habitats, but do

they facilitate or impede wildlife movement? I assessed wildlife use of seven pre-existing interstate freeway and state highway underpass structures to determine whether they are utilized as corridors for wildlife movement. The underpasses occur between southern California's Peninsular and Transverse Mountain Ranges, a key linkage between Baja California's biotic province and that of the Sierra Nevada. I utilized non-invasive monitoring methods, including camera traps, track-plates, and track beds, over 13 months to capture wildlife presence, determine rates of underpass usage, identify spatial and temporal wildlife use patterns, and to assess some factors that may constrain wildlife use. My results indicated a negative association between native carnivore presence and human activity within and near the underpass structures. Bobcats exhibited a strong negative relationship with motorized vehicles while coyotes displayed a weak negative relationship with humans on foot. Underpass dimensions influenced the rate of wildlife use, with small- and medium-bodied species preferring long, narrow structures whereas bobcats preferred structures that were wide, short, and open. Future strategies for maintaining or enhancing landscape connectivity in desert systems should provide a range of underpass structures to support use by many animals, and develop underpasses that discourage human use.

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Introduction

Free from anthropogenic disturbance, natural landscapes consist of a mosaic of interconnected habitats. Landscape connectivity is a key component for the persistence of populations as it facilitates wildlife movement, thus presumably decreasing the threat of local extirpation or even extinction. Connectivity ensures a means for species to disperse, track preferred habitat conditions in a dynamic environment, and facilitate genetic heterogeneity between populations (Noss 1987). A consequence of human development is often the loss of this original connectivity. Wildlife corridors, which connect patches of suitable habitat, can be critical conservation design components for sustaining biodiversity. With the expansion of threats such as urbanization (Chen et al. 2010), and alternative energy resource development (Kuvlesky et al. 2007), desert environments are becoming fragmented at an increasing rate. Knowledge of the environmental tolerances and movement patterns of wildlife in these areas becomes especially important to land managers responsible for ensuring population persistence. In many cases, unless corridors and linkages between suitable habitats are maintained, interconnectedness of the habitats of interbreeding populations is reduced such that isolated patches of habitats are created and the dispersal abilities of many individuals become compromised.

Connectivity- The Theoretical Basis

Habitat loss and fragmentation are currently recognized as the leading threats to biological diversity (Wilcox and Murphy 1985, Wilcove et al. 1998, Brooks et al. 2002, Fahrig 2003). Theoretically, the benefits of maintaining landscape connectivity have been

demonstrated through analogies of oceanic or land-bridge islands with terrestrial habitat islands (MacArthur and Wilson 1967, Diamond 1975, Wilcox 1980). Observations of the processes regulating populations occurring on isolated islands led to much of the ecological framework for how fragmentation, and the insular habitat patches resulting from it, affects biodiversity. Much debate has arisen within the conservation community concerning the value of this theory informing conservation practices, especially regarding the design of nature reserves (Diamond 1975, Wilson and Willis 1975, Simberloff and Abele 1976, Simberloff and Abele 1982). The debate centered on whether a single large reserve or several small reserves (known by the acronym SLOSS) would function to maximize species richness. Recognizing that these recommendations were based solely on theory, other members of the debate stressed the importance of obtaining empirical data to address this conservation question (Margules et al. 1982). Also stemming directly from island biogeographic theory, conservation strategies have emphasized maintaining connectivity among habitat patches via corridors to decrease isolation and ameliorate detrimental effects of fragmentation (Diamond 1975, Wilson and Willis 1975).

In addition to island biogeography, metapopulation theory has recently become integrated into the conceptual basis supporting corridors (Merriam 1991). Levins (1969) was the first to formalize the concept of the metapopulation with his discussion of "a population of populations" where remigration from other populations balances local extinction. Using this perspective, a metapopulation consists of a series of subpopulations that occupy spatially distinct patches and are connected by immigration and emigration of individuals between those patches (Hanski and Gilpin 1991). Rather than patches being

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uniformly distributed, metapopulation theory recognized that species occur in disconnected patches that vary across the range of the species' distribution (Hilty et al. 2006). Under metapopulation theory, any particular patch that is part of the metapopulation may be occupied at some point in time and then, due to demographic stochasticity, may become empty. If patches are connected by dispersal corridors they will subsequently be recolonized by immigrants from another patch at a higher rate than disconnected patches. Over time subpopulations shift around among occupied and empty suitable habitat patches, with the overall persistence of the metapopulation made possible due to dispersal. Man-made structures and developments can act as barriers to dispersal resulting in the inability of subpopulations to become re-established in isolated patches. The size of the metapopulation at equilibrium, as well as the probability of its persistence, suffer as a consequence. Within this theoretical framework, the design, maintenance and successful utilization of corridors is crucial for dispersing individuals to move between patches occupied by subpopulations.

This concept can be expanded to the metacommunity level, where a network of distinct, local communities are connected by the dispersal of multiple species (Leibold et al. 2004). Hanksi and Gilpin (1991) described the metacommunity as "a community of metapopulations". When examining the role of corridors at the metacommunity level it becomes apparent that different species within communities may utilize corridors in different ways. Some species may find the environment within a particular corridor sufficient for providing temporary or even permanent habitat (Barrows et al. 2011). Other species from the same community have slightly different habitat requirements and may

only utilize the corridor for direct movement between patches. Increasing the scale from metapopulation to metacommunity level increases the complexity of the role and function of corridors. This is important when trying to understand how corridors mitigate fragmentation for multiple species, especially when conservation of species having mutualistic relationships or critical trophic interactions are of concern. Island biogeography theory (MacArthur and Wilson 1963, 1967), the metapopulation (Levins 1969, Hanski and Gilpin 1991) and metacommunity (Leibold et al. 2004) concepts, as well as models of demographic stochasticity (Shaffer 1981, Soule 1987) all support the same conclusion: fragmentation, and resulting insularity increases extinction risk and accelerates biodiversity loss (Penrod et al. 2005 a,b).

Achieving Connectivity through Corridors

Embedded within an unsuitable or impermeable landscape, corridors connect suitable habitat patches that might otherwise be isolated (Beier and Noss 1998, Saunders and Hobbs 1991). Although it may be possible for connectivity to be maintained via movement through unsuitable habitat, corridors facilitate direct wildlife movement between larger patches or reserves. There are many benefits conferred upon a landscape where connectivity between patches is maintained via linkages and corridors. If effective, corridors can ameliorate the negative impacts of fragmentation and provide connectivity within a fragmented landscape. The threat of extinction or local extirpation of a population is reduced if suitable habitats are linked by corridors so that immigration from other populations is facilitated. The ability for individuals to disperse between populations also improves the possibility of a population becoming re-established in an

area where it had been extirpated (Brown and Kodric-Brown 1977). Another benefit of corridors is that they facilitate movement and dispersal across the landscape, enabling individuals to respond to changes in environment, such as tracking niche envelopes due to climate change (Hobbs and Hopkins 1991), or escaping from disturbances such as fire or habitat destruction. Landscape connectivity via corridors and linkages also ensures that the flow of genetic information among and between populations is maintained, thereby decreasing the threat of inbreeding depression that may occur in small, isolated patches (Franklin 1980, Soulé and Simberloff 1986, Keller and Waller 2002). Wide-ranging animals, such as large-bodied carnivores, require extensive ranges to sustain their needs and are especially impacted by habitat fragmentation (Haas 2000, Morrison and Boyce 2009). When forced to move through a human-dominated landscape, wildlife encounter increased contact with humans and urban development leading to mortality from poaching, vehicle collisions, predation by domestic subsidized predators (cats, dogs), and depredation by land and livestock owners (Beier 1995, Foster and Humphrey 1995, Tigas et al. 2002, Morrison and Boyce 2009).

Although the benefits of connectivity and the negative impacts of fragmentation are both widely accepted (Wilcox 1980, Wilcox and Murphy 1985, Saunders and Hobbs 1991, Noss et. al 2006), there has been much debate concerning the effectiveness of corridors as a means of providing connectivity (Simberloff and Cox 1987, Noss 1987, Hobbs 1992, Hess 1994, Beier and Noss 1998). These concerns have stemmed from the potential negative impacts of corridor implementation. One such concern is that corridors may facilitate the spread of contagious diseases among wildlife populations by enabling

the direct contact of potentially infected individuals from one population with susceptible individuals from another population (Simberloff and Cox 1987, Hess 1994). Another concern is whether poor quality corridors act as sinks for individuals of a population, causing a drain on the overall population size (Pulliam 1988). Although continuous dispersal from source to sink habitats may sustain sink metapopulations, mortality is greater than reproduction in the sink thereby decreasing or limiting the size of the overall population. Other concerns regarding corridors is the facilitation and spread of environmental disturbances such as wildfires that would otherwise be contained by the boundaries of insular habitat patches. Corridors also may enable the spread of invasive species (Simberloff and Cox 1987; for an example, see Zink et al. 1995), as well as function as artificial prey traps by predatory species (Little et al. 2002). While these concerns are relevant, few empirical studies have directly addressed these factors and their impacts on populations.

Underpasses as Corridor Linkages

Contributing significantly to habitat fragmentation is the construction of roadways, which has been estimated to cover over one percent, and ecologically impact between 15-20%, of the United States total land area (Forman and Alexander 1998). These man-made linear features can create impermeable barriers to wildlife movement, effectively severing connections between wildlife populations on both sides of the barrier unless otherwise mitigated. Roadways impact wildlife both directly and indirectly, through habitat loss and degradation, population isolation and consequent gene flow disruption, wildlife mortality from wildlife-vehicle collisions, and through behavioral

modifications such as altered movement patterns and avoidance (Bennett 1991, Jackson 1999, Bennett et al. 2011). Potentially, underpass and overpass structures may serve as critical linkages in environments that have been bisected by roadways. These structures may increase permeability by facilitating wildlife movement beneath roadway barriers, thus decreasing faunal and human mortality due to roadway collisions during crossing attempts and enabling the flow of genetic information between populations on either side of the barrier.

Studies Evaluating Underpass Use by Wildlife

Although costly to design and construct, the implementation of underpass structures as a conservation tool is becoming increasingly widespread. Numerous wildlife species have been confirmed as using underpasses to navigate highway and railway barriers in a variety of geographical locations. Examples include mountain goats (*Oreamnos americanus*) in Glacier National Park (Singer and Doherty 1985); Florida panthers (*Felis concolor coryi*), bobcats (*Lynx rufus*), deer (*Ococoileus virginianus*), raccoons (*Procyon lotor*), alligators (*Alligator mississippiensis*) and black bears (*Ursus americanus*) in Florida (Foster and Humphreys 1995); wildcats (*Felis sylvestris*), red fox (*Vulpes vulpes*), genets (*Genetta genetta*), and Iberian lynx (*Lynx pardinus*) in Central Spain (Yanes et al. 1995, Rodriguez et al. 1996); ground squirrels (*Spermophilus beecheyi*), cottontail rabbits (*Sylvilagus auduboni*), opossums (*Didelphis virginianus*), striped skunks (*Mephitis mephitis*), spotted skunks (*Spilogale putorius*), raccoons, coyotes (*Canis latrans*), bobcats, mountain lions (*Puma concolor*), and mule deer

(*Odocoileus hemionus*) in southern California (Haas 2000, Ng et al. 2004); as well as elk (*Cervus elaphus nelsoni*) in Arizona (Dodd et al. 2007).

In addition to verifying species use, studies have been conducted to evaluate factors that may constrain or encourage use (Yanes et al. 1995, Rodriguez et al. 1997, Clevenger and Waltho 2000, Ng et al. 2004, Dodd et al. 2007), underpass monitoring methods and efficacy (Bellis et al. 2007, Ford et al. 2009), and interactions that influence utilization (Little et al. 2002, Ford and Clevenger 2010).

Underpass Characteristics

A wide range of wildlife species utilize underpasses as linkages; however, differential use of underpass structures has been observed. Understanding species preference for underpass characteristics has become especially significant to wildlife managers charged with the task of maximizing connectivity for endangered or special concern species that may be particularly impacted by fragmentation. This is also important for informing transportation agencies concerned with excluding large wildlife and ungulates from roadways in an effort to reduce wildlife-vehicle collisions. Several studies identified varied factors influencing the efficacy of crossing structures. A number of studies found that structural attributes of the passages are important in determining usage (Reed et al. 1975, Clevenger and Waltho 2005, Dodd et al. 2007, Gagnon et al. 2011). For example, Clevenger and Waltho (2005) examined 13 wildlife crossing structures in Banff National Park, Canada, for 34 months post-construction and found that structural attributes were most influential for determining usage by both predator and prey species when human activity was absent. Other studies found that placement and

surrounding habitat influenced underpass use (Foster and Humphrey 1995, Yanes et al. 1995, Rodriguez et al. 1996, Ng et al. 2004). The differences between the influence of habitat, placement, and structural attributes of the underpasses on determining use can most likely be explained by species- or habitat-specific factors (Clevenger and Waltho 2005) or by inter-specific species interactions. For example, carnivores have been shown to prefer underpasses with low human activity and high vegetative cover (Rodriguez et al 1996, Clevenger and Waltho 2000, Clevenger and Waltho 2005), and small mammals tend to prefer narrow passages where the potential for predation may be low (Rodriguez et al. 1996). Ungulates are inclined to utilize passages with high openness ratios (Dodd et al. 2007). In a study of 11 underpasses in Banff National Park, Canada, ungulate use of underpass structures was determined by structural and landscape characteristics whereas carnivore use of the same underpasses was negatively related to human activity (Clevenger and Waltho 2000).

Some studies have found that wildlife may become habituated to newly constructed underpasses over time thus decreasing the influence of structural characteristics. Gagnon et al. (2011) evaluated habituation of elk and white-tailed deer to six newly constructed underpasses in Arizona. During the first year of monitoring post-construction, one underpass had a particularly low probability of successful elk crossings (0.20 crossings / approach) owing to its obstructed view of habitat on the other end of the underpass. By the fourth year however, the probability had increased to 0.70 crossings / approach indicating adaptation to the structural characteristics of the underpass. Interestingly, the probability of successful elk crossings at another of the underpasses,

which was small and located near an area with almost constant human presence, decreased from 0.13 to 0.02 elk crossings/approach over the four-year monitoring period. However this underpass had the highest probability for successful white-tailed deer crossings, indicating that, unlike elk, deer were better able to adapt to the landscape conditions as well as the structural attributes of the underpass over time.

Monitoring Methods and their Efficacy

Several methods have been used to verify wildlife use of underpass structures (Hardy et al. 2003), and several studies have focused on evaluating the efficacy of these methods (Bellis et al. 2007, Ford et al. 2009). Bellis et al. (2007) utilized a variety of methods to monitor underpass use by multiple taxa, highlighting that a combination of techniques is most effective when monitoring for multiple species. Ford et al. (2009) compared two of the most popular non-invasive underpass monitoring methods (motion-activated cameras and track beds) in an empirical study to evaluate whether there were species-specific detection biases and to determine cost-effectiveness. They found that the detection of coyotes, wolves, and grizzly bears were biased towards the track bed method, whereas large-bodied, slow moving species such as black bears, cougars, deer, and elk were more likely to be detected by the camera method. They also determined that it was more economical to use a camera-only approach when study durations lasted longer than one year, especially when wildlife crossings per month were high, since track bed quality degraded with increased animal activity. For shorter duration studies, track beds were the more economical option as they have lower start-up costs; however, their limitations include lower confidence in species identification and a tendency toward

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identification biases if multiple technicians are identifying tracks. Among the advantages of camera surveys was their insensitivity to weather conditions, reliable species identification, and additional information such as group size, behavior of individuals, and timing of crossing events.

Interactions Influencing Underpass Effectiveness

A concern that has been voiced is the potential for underpasses to be used advantageously as prey traps by predatory species, thus decreasing the structure's conservation value (Little et al. 2002). Little et al. (2002) reviewed underpass monitoring literature and found that there was little evidence to suggest that crossing structures facilitate the exploitation of prey. They concluded predation events were most likely opportunistic. In a study monitoring movements and habitat preferences of radio collared cougars, Dickson et al. (2005) found that none of the 85 recorded deer kill sites and only 2 of the 60 small mammal kill sites were within 300 m of an underpass structure. Ford and Clevenger (2010) documented underpass use by large carnivores and ungulates before and after the structures had been constructed and observed only five kill sites near crossing structures out of 32,000 documented visits. Although few studies have addressed the potential for underpass structures to be utilized as prey traps by predatory species, the little evidence that currently exists does not support the prey trap hypothesis (Little et al. 2002, Dickson et al. 2005, Ford and Clevenger 2010).

Although previous studies have not verified the use of underpasses as prey traps, there is evidence that prey species may avoid interactions with predators by utilizing different structures or crossing at different times of the day (Little et al. 2002). Despite

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limited replications, during their study of four underpasses in Florida Foster and Humphrey (1995) observed the highest percentage of human and bobcat crossings at one underpass while white-tailed deer crossings were highest in the other three underpasses. They also found that while Florida panthers crossed only at night, the majority of white-tailed deer crossings occurred during the day. Rodriguez et al. (1996), in their study of seventeen culverts beneath a high speed railway in Spain, reported an apparent preference of carnivores for structures with vegetative cover at their openings whereas small mammals used narrow structures that secured them from overhead predators. In Banff National Park, Clevenger and Waltho (2000) found ungulates avoided underpasses near drainages whereas large carnivores, such as mountain lions, black bears, and wolves, tended to prefer those underpasses. Additionally they found that carnivores were less likely to use the underpasses than ungulates when human activity was present.

Do Underpasses Link the Peninsular and Transverse Mountain Ranges?

Habitat connectivity is a key component for the persistence of populations, for maintaining genetic diversity, and for weathering environmental extremes and climate shifts. Desert environments are stressful largely because of extreme swings in precipitation and temperature, and thus connectivity becomes a critical conservation strategy to ensure mobile species can track temporal and spatial shifts in habitat suitability. These linkages are especially critical to providing potential routes for species tracking their niche envelopes in light of expected distributional shifts due to climate change (Hobbs and Hopkins 1991, Halpin 1997, Williams et al. 2005). The California

Floristic Province is among 25 hotspots that have been identified globally as areas having both the greatest concentration of biodiversity and threats to that biodiversity, and is therefore a high priority area for focused conservation efforts (Mittermeier et al. 1998, Myers et al. 2000). As urban expansion begins to reach its limits in the coastal areas of California, and as opportunities for alternative energy resource development are realized, California's desert regions are beginning to experience increased development and fragmentation (Chen et al. 2010). Highways exacerbate fragmentation by creating linear barriers to wildlife movement, which then interrupts gene flow, alters wildlife behavior and isolates populations (Bennett 1991, Jackson 1999). Underpass structures beneath highway systems potentially ameliorate the effects of roadway barriers by serving as critical linkages. Corridor studies focusing on underpasses located in arid or desert environments are rare, and only within the last decade have such studies begun to emerge (see Dodd et al. 2007, Bristow and Crabb 2008).

The focus of this study was to evaluate the use of highway underpasses as wildlife corridor linkages between the Peninsular and Transverse mountain ranges, in southern California. My objectives were, first, to determine whether wildlife utilize existing underpass structures and the rate of that use; second, to identify spatial and temporal wildlife use patterns; and third, to assess factors, such as structural attributes and human activity, that may constrain wildlife use.

Materials and Methods

Study Area

The landscape linkage between the Peninsular and Transverse mountain ranges is located

in the western portion of the Coachella Valley, Riverside County, California, USA (Fig.

1). A human population increase of 200% between 1980 and 2002 made Riverside

County the fastest growing county in California, with more residents than in 13 other

states (Chen et al. 2010,

http://www.countyofriverside.us/visiting/aboutriverside/riversidecounty.html). This

increased growth accelerated fragmentation and decreased landscape permeability for

dispersing wildlife. This area is situated in a zone where three ecoregions, the South

Coast, Mojave Desert, and Sonoran Desert, converge (Fig. 2). It is also where flora and

fauna with affinities to Baja California (in the San Jacinto and Santa Rosa Mountains of

the Peninsular Range) meet those with affinities to the Sierra Nevada and further north

(in the San Bernardino Mountains of the Transverse Range). This geographic and

ecological juxtaposition results in a region rich in biodiversity and is the closest point of

connection for facilitating wildlife movements between these two mountain ranges

(Penrod et al. 2005b).
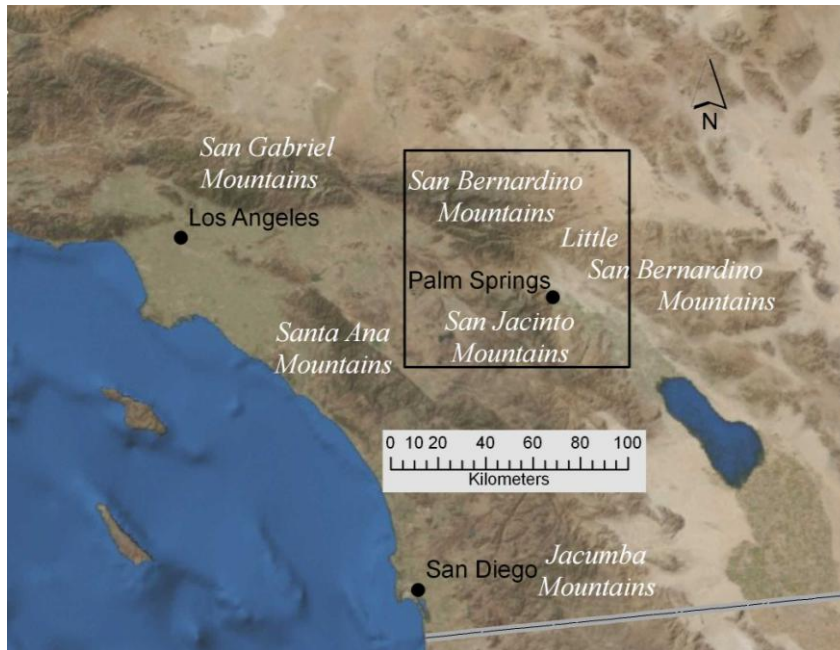
Figure 1. Southern California; a black box encloses the study region. The San Jacinto Mountains are part of the Peninsular Ranges and the San Bernardino and Little San Bernardino Mountains are both part of the Transverse Range.
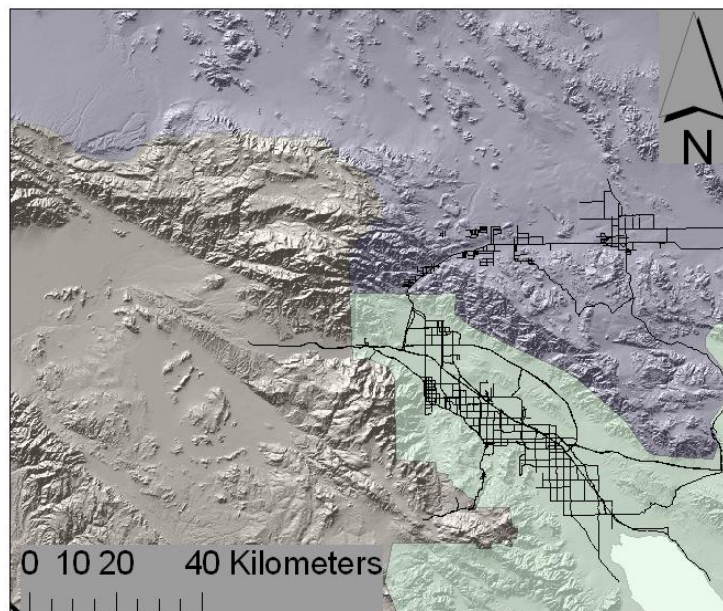
Figure 2. Three ecoregions converge in the study area region: South Coast (orange shading), Mojave Desert (purple shading) and the Sonoran Desert (green shading).

San Jacinto - San Bernardino Mountain Range Linkage

The San Jacinto – San Bernardino mountain range linkage has been identified as a critical

connection between the Peninsular and Transverse mountain ranges in southern

California (Penrod et al. 2005b). The Interstate-10 highway (hereafter referred to as I-10)

runs through the Coachella Valley and is bordered on the north by the San Bernardino

Mountains and to the south by the San Jacinto Mountains. I-10 is an eight lane highway

bisecting these two mountain ranges and may present a significant barrier to wildlife

movement (Fig. 3). Several underpass structures are located along I-10 allowing water

runoff from snow pack melt to flow unimpeded beneath the highway and a parallel

railway. Although not specifically designed for wildlife crossings these underpass

structures may be functioning as important linkages by facilitating the movement of

wildlife utilizing the corridor.
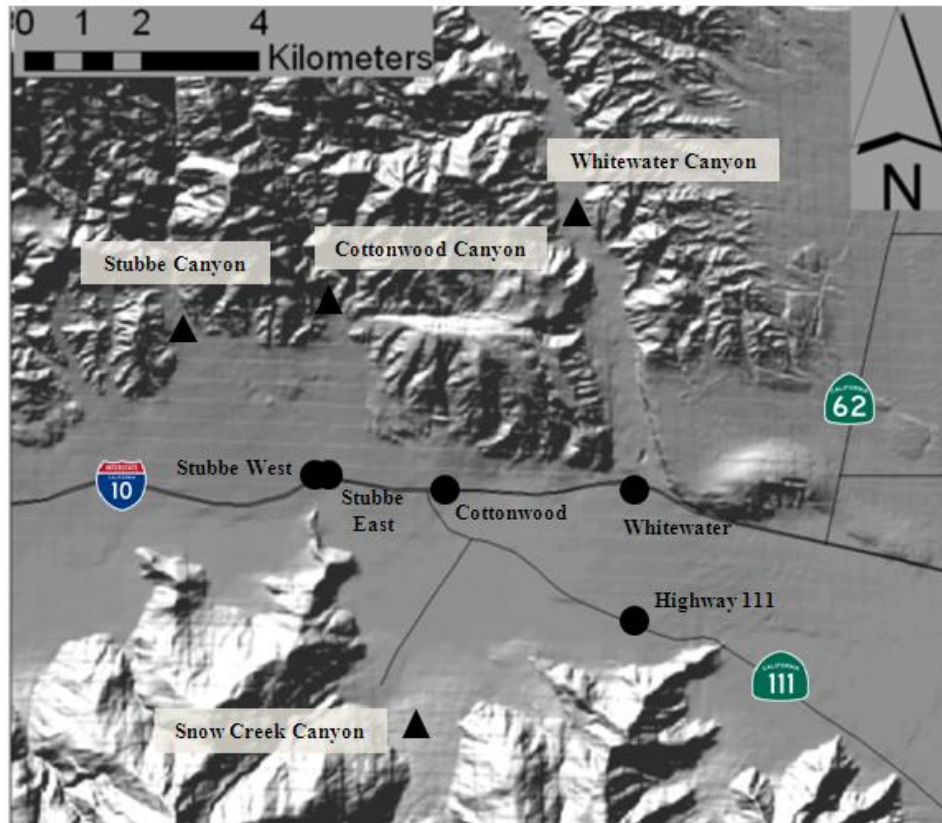
Figure 3. Canyons and corresponding underpasses between the San Bernardino Mountains to the north and the San Jacinto Mountains to the south. Interstate-10 and Highway-111 bisect these two mountain ranges. Underpass locations are indicated by black circles. Canyon locations are indicated by black triangles.

Interstate-10 Underpass Structures

Stubbe Canyon and its corresponding underpasses are the western-most of the linkages, emerging north of I-10 from the southern edge of the San Bernardino Mountains (Fig. 3). Separated by a distance of 30-m, two underpass structures (Stubbe East and Stubbe West) run beneath the I-10 highway and adjacent railway (Fig. 6a and 6b). Both structures are similar in dimensions, with the only exception being the shape of the railway bridge at the underpasses southern openings. Stubbe East is used frequently by maintenance

vehicles and hikers on the Pacific Crest Trail whereas Stubbe West is used only occasionally by off-highway vehicles and humans. Access by full-sized vehicles is limited due to erosion from flood events. Both structures contain atria, which are uncovered openings in the ceiling of the underpass where the two directions of highway traffic are separated (Fig. 4). These atria allow natural light to illuminate the center of the underpass during the day and may facilitate growth of vegetative cover within the underpass. The substrate within the structures is natural and is comprised of hard packed soil, gravel, sand, and sandy loam.

Figure 4. Photograph of a characteristic atrium taken from the entrance of Stubbe West underpass. The atrium is an opening in the underpass where the two directions of highway traffic are separated allowing for light to naturally illuminate the underpass.

Cottonwood Canyon is located east of Stubbe Canyon at the base of the San Bernardino Mountains (Fig. 3). The wash leading out of the canyon is modified into a concrete channel as it approaches the I-10 culvert from the north, and consists of natural substrate to the south.

Cottonwood underpass differs from the other possible linkages beneath I-10 in that it is the only culvert structure (Table 1, Fig. 6c). Concrete support walls run the length of the underpass and completely separate each of the three chambers. The substrate within the underpass is mostly sand, although the concrete floor of the culvert is exposed in some spots near the northern opening due to wind.

Whitewater Canyon is the easternmost of the canyons and corresponding underpasses along I-10. Whitewater River flows through the canyon offering riparian habitat for a number of species. The canyon has been identified as a primary potential route of movement by mountain lions (Penrod et al. 2005b), using Whitewater underpass as a linkage between the mountain ranges. The underpass consists of several large chambers containing rocky outcroppings against all support walls, with the highest openness ratio (calculated as height x width/ length) of all structures studied (Table 1, Fig. 6d). Substrate is natural, and the visibility through the underpass is high. Due to the river which flows through it, this underpass is frequently used by humans for recreational activity.

Another barrier, the four-lane State Route 111, is located between the San Jacinto Mountains and the I-10 underpass structures to the north (Fig. 3). A bridge underpass beneath this highway, heretofore called Highway 111 underpass, contains one atrium (Table 1, Fig. 6e) and the substrate consists of fine sand, which contributes to the sand dune habitat to the south of this underpass. Although this area is closed to off-highway vehicle activity, vehicles are frequently observed accessing the area via this underpass structure. South of State Route 111, at the base of the San Jacinto Mountains, Snow Creek Canyon and Oasis de los Osos are the

likely points of arrival and departure for a species traversing this corridor to and from the south.

San Bernardino – Little San Bernardino Mountain Range Linkage

The San Bernardino-Little San Bernardino connection is a critical corridor linkage for maintaining connectivity between the Transverse Mountain Ranges, (including the San Bernardino Mountains) to the west and the Little San Bernardino Mountains and Joshua Tree National Park (in the Mojave Desert) to the east (Penrod et al. 2005a). Two underpass structures located along State Route 62 (hereafter referred to as SR-62) were included in this study. SR-62, a four lane highway, branches off of the I-10 freeway north of Palm Springs, California, and travels between the area where the San Bernardino mountains converge with the Little San Bernardino mountains, presenting a significant barrier to wildlife movement (Fig. 5). Two canyons, Dry Morongo canyon and Mission Creek canyon, emerge from the eastern edge of the San Bernardino Mountains. Underpass structures associated with these canyons were constructed along SR-62 to allow water to flow unimpeded beneath the highway.
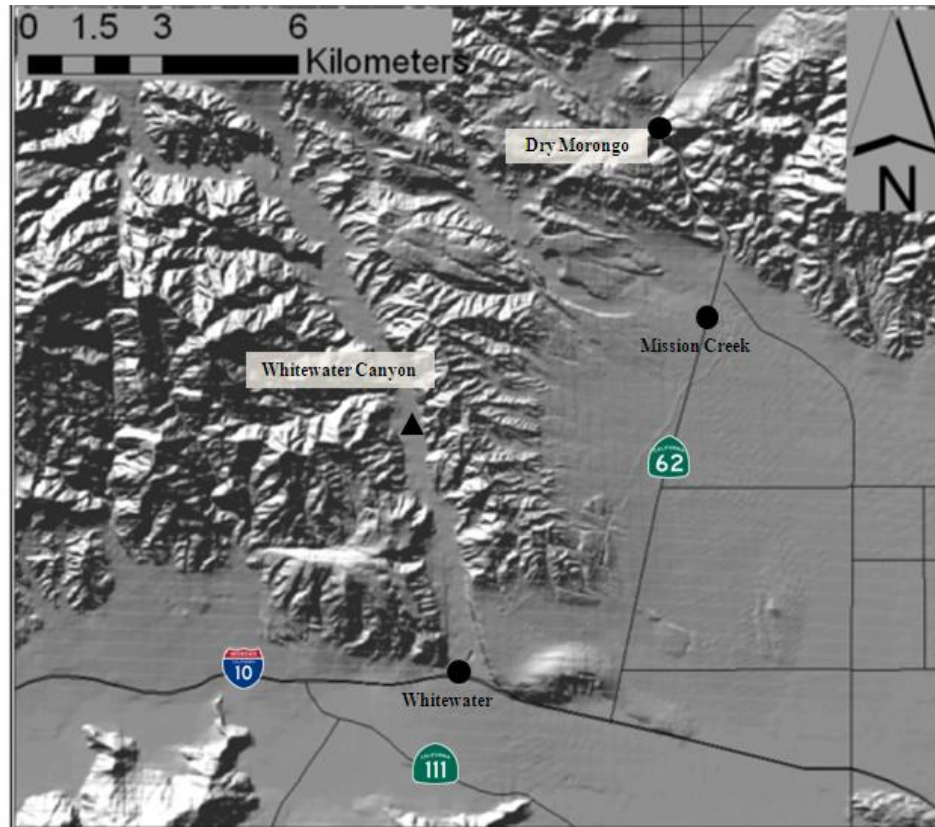
Figure 5. Dry Morongo and Mission Creek underpasses between the San Bernardino mountains to the northwest and the Little San Bernardino mountains to the northeast along State Route 62. Underpass locations are indicated by black circles. Canyon locations are indicated by black triangles. Whitewater canyon and underpass are included for reference.

State Route-62 Underpass Structures

Dry Morongo canyon is located on the border of Riverside and San Bernardino county and is

the northern-most of the canyons and corresponding underpasses along SR-62 in this study. Of

all the underpasses included in this study, Dry Morongo underpass is closest to the mountain

ranges on either side of the underpass openings, is the only underpass lacking an atrium, and

has the second highest openness ratio (Table 1, Fig. 6f). Visibility through the underpass is

high and the substrate consists of natural material. Several homes exist at the mouth of the

canyon to the west of the underpass opening and the underpass is used frequently by humans

on foot, and by off-highway and full-sized vehicles, which frequently access the underpass from the west.

Mission Creek canyon is located south of Dry Morongo canyon and north of Interstate-10. Two underpass structures, approximately 600-m apart, were constructed to allow both branches of the Mission Creek wash and seasonal stream to flow beneath the highway. The seasonal stream flows through the southern Mission Creek underpass and it was this underpass that was originally chosen for monitoring; however constant vandalism of the cameras made it necessary to move monitoring to the northern "dry" underpass where human activity was less frequent. The underpass consists of two main chambers and an atrium, with earthen substrate throughout (Table 1, Fig. 6g). Vegetative cover is dense, and the topography uneven at the eastern opening of the structure making it difficult for off-highway and full-sized vehicles to traverse the underpass.

Characteristics of the Underpass Structures

Of the seven underpass structures included for monitoring in this study (Fig. 6), six were bridged underpasses and one was a culvert structure. Length (measured from opening to opening, including the span of the atrium when present), width (full span of the opening, including all chambers), height (from the ceiling of the structure to the substrate) were obtained by the author and supplemented by Penrod et al. (2005a, 2005b) (Table 1). These characteristics, as well as openness (height x width / length), and extent of human activity near the underpass, were used as predictor variables for wildlife use. All underpasses (with the exception of Dry Morongo underpass) contain an atrium, and most consist of several chambers that are formed by support beams running the length of the structure. Being that each

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underpass was constructed to allow natural washes to flow unimpeded beneath the highway, substrate within most of the underpasses is natural, comprised of dirt, gravel, or sand deposited from wind and water. Cottonwood underpass is the exception as it has a concrete bottom that is exposed in patches due to water and sand movement.

Table 1. Characteristics of the seven underpass structures monitored in this study.

Underpass Attributes	Underpass						
	Stubbe West	Stubbe East	Cottonwood	Whitewater	Highway 111	Mission Creek	Dry Morongo
Width (m)	11.5	17	39	150	68	30.5	18.3
Length (m)	112	112	77	48.2	37	44.5	12.2
Height (m)	4.5	4.5	2.9	9	2.5	5.4	7.6
Openness	0.46	0.68	1.47	28.01	4.59	3.70	11.40
Type of Passage	Bridge	Bridge	Culvert	Bridge	Bridge	Bridge	Bridge
Highway location	I-10	I-10	I-10	I-10	Highway 111	SR-62	SR-62
Substrate	Natural	Natural	Concrete bottom with sand deposition	Natural	Natural	Natural	Natural
Atrium Present	Yes	Yes	Yes	Yes	Yes	Yes	No
Number of Chambers	1	1	3	8	7	4	1
Habitat on other side of structure clearly visible?	No	No	Yes	Yes	Yes	No, blocked by vegetation	Yes

Measured by the author and supplemented by Penrod et al. (2005a, 2005b). Width is measured from main wall to main wall, including all chambers. Length is measured as the complete distant between each opening, including the span of atria, when present. Height varies depending on sand deposition. Openness is calculated by (W*H)/L, with larger values indicating greater openness.

Figure 6. Photographs of the seven underpass sites. (a.) Stubbe East, (b.) Stubbe West (c.)
Cottonwood, (d.) Whitewater, (e.) Highway 111, (f.) Dry Morongo, and (g.) Mission Creek.

Sampling Techniques

Camera Surveys

To document species use of the underpass structures I deployed infrared motion detection cameras with night vision (DLC Covert II, 4338 Greenridge Spa Road, Lewisburg, KY 42256). A camera was set up at each end of all underpasses and positioned to aim across the face of the underpass opening. Cameras were placed low to the ground to decrease detection by humans as well as increase detection of small wildlife species. In the event of human or animal movement near the underpass opening the camera was triggered to take three photos in one second intervals. Photographs taken by the cameras allowed the distinction between species with similar tracks, such as domestic dogs and coyotes, or cottontail rabbits and jackrabbits. Species identification, date, time, direction of travel, and type of activity were recorded for each detection event. Rate of underpass usage was determined by dividing the number of detections of a species by the number of days the camera was active per site.

Track Bed and Sooted Track Plate Surveys

To complement the camera surveys, track beds (Rodriguez et al. 1996) and sooted aluminum track-plate stations (Taylor and Raphael 1988) were deployed at each underpass opening to record the tracks of animals utilizing the corridor. These methods enabled me to capture the movement of small bodied mammals and reptiles that may not have triggered the motion sensor cameras. Track beds consisted of 1-meter wide swaths of sandy substrate spread evenly across the entire width of each underpass opening. The

majority of the underpasses surveyed had naturally occurring sandy substrates; in underpasses where substrate was inadequate, supplements of sand were required to develop and maintain a track bed. During each visit to the underpass, tracks left in the sand of the track bed were inspected and species identification and direction of travel were recorded. The track bed was then smoothed with a broom to eliminate all tracks ensuring only new tracks would be recorded during subsequent surveys. On average, surveys were conducted three times per month per site. During winter months, when flooding and inclement weather prevented site access, surveys were conducted at least once per month per site. At sites where theft was frequent, surveys were conducted once per month, on average.

Sooted aluminum track stations consisted of two 40.6-cm x 81.3-cm (16-in x 32-in) sheets of 24 gauge galvanized aluminum sheets, to which a light layer of soot was applied by an acetylene gas torch. When an animal walked onto the plate soot was transferred from the plate to the animal's paw leaving behind an imprint of the track by which I could identify the species (Fig. 7). Rates of occurrence at the underpass were recorded as the number of occurrences of a particular species at a track bed or plate divided by the number of days the track bed or plate was sampled.

Figure 7. An example of a sooted aluminum track plate station with canid tracks.

Road Mortality Surveys

Opportunistic surveys for wildlife road kill occurrences upon SR-62 and I-10 were

conducted one to two days per week by car on days when underpasses were sampled.

Surveys began approximately 1-km before the first underpass (Stubbe West) and ended

approximately 1-km after the last underpass (Dry Morongo). The total length of roadway

surveyed was approximately 22.5-km in each direction of travel. Date, approximate

locations, and size estimates of wildlife were recorded when road kill was encountered.

Road mortality data was used to examine potential patterns and frequency of wildlife

entering directly upon the highway surface.

Analysis

Due to non-normality, non-parametric tests were used to analyze the data. As with similar

studies (Yanes et al. 1995, Ng et al. 2004), Spearman's rank correlation (MATLAB

Version 7.7.0, R2008b) was used to quantify the relationship between use of the underpass structures by wildlife and underpass characteristic variables, which include structural attributes (length, width, height, and openness) and extent of human activity near each underpass. Human activity consisted of five categories: (1) rate of full-sized vehicles, (2) rate of off-highway vehicles, (3) rate of humans on foot, (4) total human use, calculated as the rates of the three previous categories combined, and (5) the rate of canids. Due to the difficulty of distinguishing between domestic canine and coyote by tracks, only camera data were used in the Spearman's rank correlation analysis when the relationships for those species were examined. For all other species camera and track data were combined.

The Mann-Whitney U test was used to detect differences in the rates of wildlife use and human activity between sites deemed "good" versus sites deemed "compromised" (Table 2). Sites were first analyzed according to amount of human related activity, with sites having crossing rates of <0.5 for total human activity being placed in the "good" category (n = 9) and all other sites being placed in the "compromised" category (n = 5). For the second analysis, sites were divided according to nearby vegetative cover and quality (Table 2). Sites in close proximity to human habitation or roads and sites lacking vegetative cover were placed into the "compromised" category (n = 5) and all other sites were placed in the "good" category (n = 9). To identify the potential for both Type I and Type II errors, p-values are reported for each relationship discussed. Previous studies have adopted $\alpha = 0.10$ as a measure of statistical significance, due to small sample size and the use of non-parametric tests (see

Ng et al. 2004), however the reader may wish to adjust measures of statistical

significance down to account for the multiple simultaneous tests of each predictor

variable.

Table 2. Classification of each underpass opening based on rate of human activity and nearby vegetation quality and cover

Underpass	Opening	Rate of Human Activity Classification	Nearby Vegetation Quality and cover Classification
Stubbe West	North	Compromised	Compromised
	South	Good	Good
Stubbe East	North	Compromised	Compromised
	South	Compromised	Good
Cottonwood	North	Good	Compromised
	South	Good	Good
Whitewater	North	Good	Good
	South	Good	Good
Highway 111	North	Good	Compromised
	South	Good	Good
Mission Creek	East	Good	Good
	West	Good	Good
Dry Morongo	East	Compromised	Good
	West	Compromised	Compromised

Results

In total 1,846 wildlife occurrences and 906 human-related activities were recorded as

tracks and photos near the underpasses during the 13-month monitoring period (Table 3).

Of wildlife detections, 74 (4.0%) were of reptiles, 192 (10.4%) were of birds (Figure 8a),

821 (44.5%) were of small mammals (Figure 8b; includes ground squirrel species, and

small rodent species), 442 (23.9%) were of medium-sized mammals (Figure 8c; includes

desert cottontails, black-tailed jackrabbits (*Lepus californicus*), striped skunks, raccoons, and domestic felines), and 317 (17.2%) were of large-bodied mammals (Figure 9a-c; includes bobcats, coyotes, gray fox (*Urocyon cinereoargenteus*), mountain lions, mule deer and domestic canines). Of the human related activities detected, 454 (50.1%) were of humans on foot, 351 (38.7%) were of full-sized vehicles, and 101 (11.2%) were of off-highway vehicles.
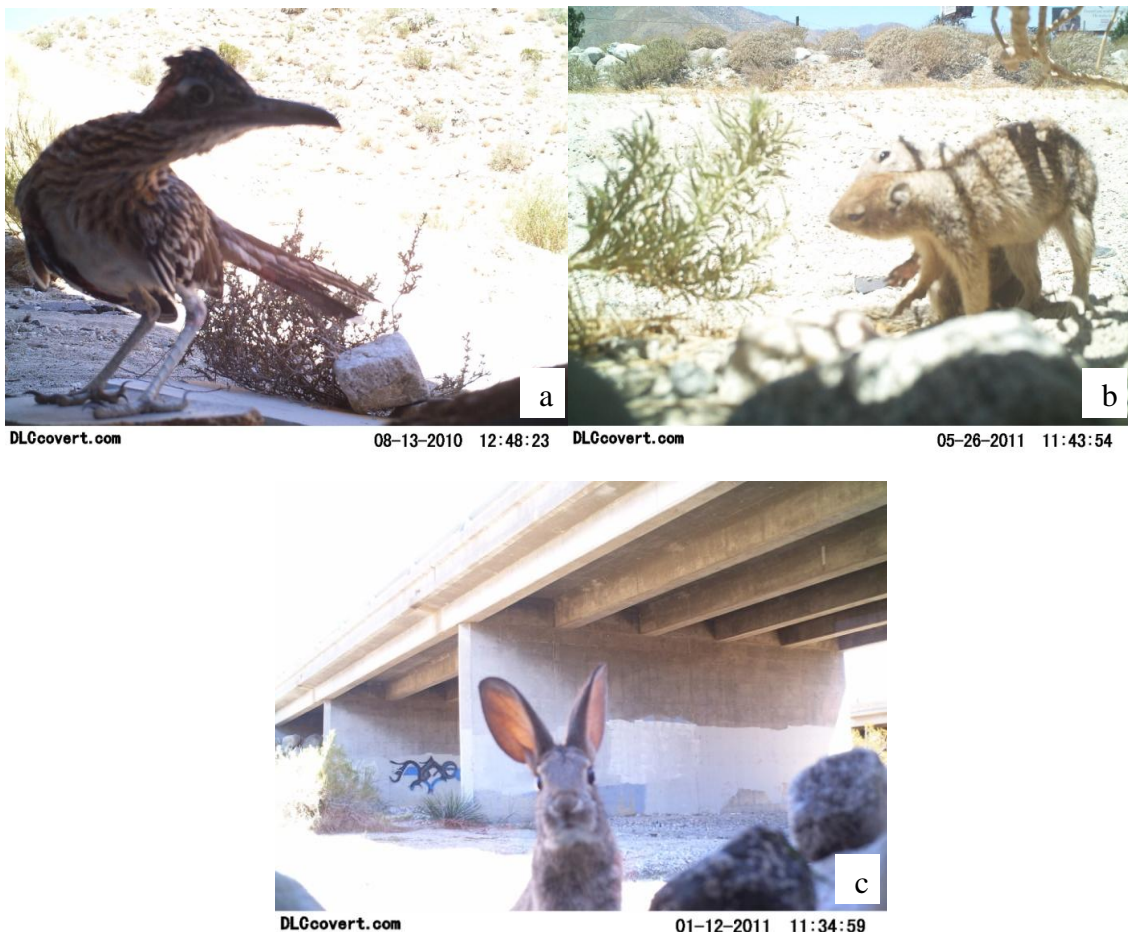
Figure 8. (a) Greater roadrunner near the eastern opening of Dry Morongo underpass, (b) two California ground squirrels at the southern opening of Cottonwood underpass, and (c) Desert cottontail near the western opening of Mission Creek underpass.

Figure 9. (a) Bobcat travelling south from Highway 111 underpass toward the San Jacinto Mountains, (b) coyote travelling north within Snow Creek Canyon towards Highway 111, (c) mule deer travelling west at the entrance of Dry Morongo underpass.

Relationships between Underpass Structural Attributes and Wildlife Use

Small rodent species (including, but not limited to, deer mice (*Peromyscus* spp.), pocket mice (*Perognathus* spp.), kangaroo-rats (*Dipodomys* spp.), and woodrats (*Neotoma* spp.)) had a positive trend with underpass height ($r_s = 0.677$, $P = 0.117$; Table 4). Ground squirrel species (including California ground squirrel (*Spermophilus beecheyi*), round-tailed ground squirrel (*Spermophilus tereticaudus*), and white-tailed antelope ground squirrel (*Ammospermophilus leucurus*)) were negatively associated with

underpass width and openness ratios ($r_s = -0.786$, $P = 0.0480$ and $r_s = -0.857$, $P = 0.0238$ respectively) and positively associated with underpass length ($r_s = 0.811$, $P = 0.0381$). Medium-bodied mammals were also negatively associated with underpass width and openness ratios ($r_s = -0.821$, $P = 0.0341$ and $r_s = -0.929$, $P = 0.006$, respectively) and were positively associated with underpass length ($r_s = 0.739$, $P = 0.0706$). The rates of coyote and all canids together were negatively associated with underpass width ($r_s = -0.899$, $P = 0.278$ and $r_s = -0.821$, $P = 0.0341$, respectively), whereas the rates for domestic canines were not ($r_s = -0.174$, $P = 0.756$).

Relationships between Human Activity and Wildlife Use

Small rodent species has a weak positive trend with humans on foot and total human activity (both $r_s = 0.643$, $P = 0.139$; Table 5). Ground squirrel species and medium-bodied mammals were each positively associated with off-highway vehicle use ($r_s = 0.739$, $P = 0.0706$ and $r_s = 0.793$, $P = 0.039$, respectively); however, this could be due to the weak trend of off-highway vehicle activity near underpasses with low openness ratios ($r_s = -0.595$, $P = 0.1698$; Table 6), an attribute which is highly associated with both wildlife groups. Bobcat crossing rates were negatively associated with full-sized vehicles ($r_s = -0.901$, $P = 0.0095$), off-highway vehicles ($r_s = -0.927$, $P = 0.0079$) and canids (coyotes and domestic canines; $r_s = -0.703$, $P = 0.0897$). The rate of canid (coyotes, gray fox, and domestic canines) occurrence was positively associated with off-highway vehicles ($r_s = 0.829$, $P = 0.0302$).

Using only camera data to accurately distinguish between coyotes and domestic canines revealed that coyotes had a weak positive trend with off-highway vehicles ($r_s =$

0.574, P = 0.244), as did domestic canines (r_s = 0.544, P = 0.261). Although weak trends exist, human activity was not significantly correlated with any of the passage attributes (Table 6).

The Mann-Whitney U test was used to detect differences between sites categorized as good versus compromised on the basis of human activity (Table 7). The test revealed that the crossing rates of small-bodied mammals (U = 3.378, P = 0.0530), medium-bodied mammals (U = 9.00, P = 0.0027), canids (U = 9.00, P = 0.0027), and all wildlife analyzed together (excluding canids; U = 5.44, P = 0.02) were lower in sites categorized as "good" versus sites categorized as "compromised". The crossing rates of bobcats were not different between good versus compromised sites (U = 0.55, P = 0.458), which is likely due to their propensity to utilize the underpasses during times when human activity is least likely (Fig. 10).

For sites categorized as good versus compromised on the basis of habitat quality and proximity to human developments, the Mann-Whitney U test detected differences between the crossing rates of medium-bodied mammals (U = 2.778, P = 0.096) which were lower at "good" versus "compromised" sites (Table 7). Differences were also detected for rates of full-sized vehicles (U = 3.247, P = 0.072) and total human activity (U = 2.778, P = 0.0960) which were higher at "compromised" sites.

Road Mortality

Data from road mortality surveys along I-10 and SR-62 revealed that road mortality was infrequent and averaged approximately seven road killed animals per month. Road kill 6-12 inches in length (cottontail, jackrabbits, ground squirrels and

domestic cat; n = 54), followed by <6 inches in length (small rodents, birds, and lizards; n = 22) were most commonly observed. Large road kill, such as raccoons, domestic canine, and coyote (adult and juvenile) were the least frequently observed (n = 12). Gray fox mortality was observed upon SR-62 (K. Fleming, Center for Conservation Biology, *pers. comm.*) but not on any other highway. No deer or bobcat mortalities were recorded upon any of the highways.
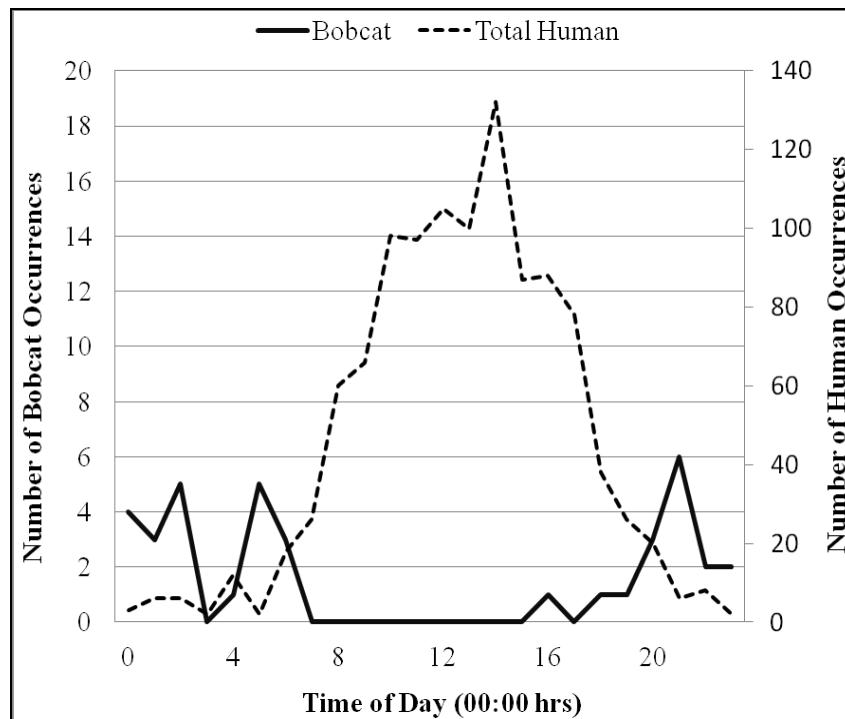
Figure 10. Number of bobcats utilizing the underpass structures by time of day compared to humans. Total human count includes full-sized vehicles, off-highway vehicles, and humans on foot.

Table 3. Crossing rates of wildlife at each underpass site. (Rate = No. of occurrences per species / No. of monitoring days)

	Stubbe East		Stubbe West		Cottonwood		Whitewater		Highway 111		Dry Morongo		Mission Creek	
No. of Days Monitored	17		299		354		381		351		333		229	
Species	**N**	**Rate**	**N**	**Rate**	**N**	**Rate**	**N**	**Rate**	**N**	**Rate**	**N**	**Rate**	**N**	**Rate**
Reptile species	3	0.1765	6	0.0201	15	0.0424	14	0.0367	17	0.0484	13	0.0390	6	0.0262
Small rodent species- Pocket mouse (*Perognathus* spp.), kangaroo rat (*Dipodomys* spp.), woodrat (*Neotoma* spp.), deer mouse (*Peromyscus* spp.)	15	0.8824	42	0.1405	108	0.3051	227	0.5958	21	0.0598	182	0.5465	90	0.3930
Ground squirrel species- California ground squirrel (*Spermophilus beecheyi*), round-tailed ground squirrel (*Spermophilus tereticaudus*), white-tailed antelope ground squirrel (*Ammospermophilus leucurus*)	5	0.2941	55	0.1839	32	0.0904	9	0.0236	3	0.0085	15	0.0450	17	0.0742
Bird species	8	0.4710	21	0.0702	14	0.0395	17	0.0446	17	0.0484	86	0.2583	29	0.1266
Desert cottontail (*Sylvilagus audubonii*)	11	0.6471	164	0.5485	85	0.2401	15	0.0394	10	0.0285	47	0.1411	39	0.1703
Black-tailed jackrabbit (*Lepus californicus*)	2	0.1176	2	0.0067	7	0.0198	2	0.0052	13	0.0370	3	0.0090	13	0.0568
Striped skunk (*Mephitis mephitis*)	0	0.0000	0	0.0000	1	0.0028	1	0.0026	0	0.0000	2	0.0060	0	0.0000
Raccoon (*Procyon lotor*)	1	0.0588	0	0.0000	0	0.0000	6	0.0157	1	0.0028	0	0.0000	1	0.0044
Domestic cat	0	0.0000	3	0.0100	8	0.0226	1	0.0026	4	0.0114	0	0.0000	0	0.0000

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Table 3. (Continued)

Species	Stubbe East		Stubbe West		Cottonwood		Whitewater		Highway 111		Dry Morongo		Mission Creek	
	N	Rate	N	Rate	N	Rate	N	Rate	N	Rate	N	Rate	N	Rate
Canid species- Domestic dog, coyote (*Canis latrans*), gray fox (*Urocyon cinereoargenteus*)	13	0.7647	29	0.0970	28	0.0791	28	0.0735	28	0.0798	120	0.3604	17	0.0742
Bobcat (*Felis rufus*)	0	0.0000	3	0.0100	0	0.0000	9	0.0236	5	0.0142	3	0.0090	18	0.0786
Mountain Lion (*Puma concolor*)	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000	5	0.0150	0	0.0000
Mule deer (*Odocoileus hemionus*)	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000	2	0.0060	0	0.0000
Horse and burro	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000	9	0.0270	0	0.0000
Human	34	2.0000	40	0.1338	35	0.0989	143	0.3753	69	0.1966	122	0.3664	11	0.0480
Off-highway Vehicle	13	0.7647	16	0.0535	28	0.0791	7	0.0184	9	0.0256	22	0.0661	6	0.0262
Full-sized Vehicle	169	9.9412	10	0.0334	44	0.1243	4	0.0105	40	0.1140	84	0.2523	0	0.0000

Table 4. Spearman rank correlation coefficient values for underpass structural variables and rates of wildlife crossings.

Species	Length	Width	Height	Openness
Small rodent species	0.162 (0.729)	-0.071 (0.906)	0.667 (0.117)	0.214 (0.662)
Ground squirrel species	**0.811 (0.0381)**	**-0.786 (0.0480)**	-0.126 (0.798)	**-0.857 (0.0238)**
Medium-bodied mammals	**0.739 (0.0706)**	**-0.821 (0.0341)**	-0.342 (0.459)	**-0.929 (0.0067)**
Canid	0.396 (0.378)	**-0.821 (0.0341)**	0.144 (0.757)	-0.500 (0.267)
Coyote	-0.232 (0.672)	**-0.899 (0.0278)**	0.116 (0.839)	-0.319 (0.556)
Domestic Canine	-0.232 (0.667)	-0.174 (0.756)	0.493 (0.344)	0.232 (0.667)
Bobcat	-0.391 (0.383)	0.414 (0.356)	0.373 (0.407)	0.450 (0.311)

Statistical relationships are indicated in parentheses. All categories were calculated from camera and track data combined, with the exception of coyote and domestic canine, which were calculated from camera data only.

Table 5. Spearman rank correlation coefficient values for human activity variables and rates of wildlife crossings.

Species	Full-Sized Vehicle	Off-Highway Vehicle	Humans on Foot	Total Human	Canid
Small rodent species	0.286 (0.556)	0.234 (0.623)	0.643 (0.139)	0.643 (0.139)	0.500 (0.267)
Ground squirrel species	0.357 (0.444)	**0.739 (0.0706)**	0.000 (0.000)	0.000 (0.000)	**0.786 (0.048)**
Medium-bodied mammals	0.429 (0.354)	**0.793 (0.0397)**	-0.071 (0.906)	-0.036 (0.964)	**0.750 (0.066)**
Canid	0.679 (0.120)	**0.829 (0.0302)**	0.321 (0.498)	0.429 (0.354)	----
Coyote	0.261 (0.617)	0.574 (0.244)	-0.319 (0.556)	-0.029 (0.983)	----
Domestic Canine	0.232 (0.667)	0.544 (0.261)	0.058 (0.939)	0.203 (0.722)	----
Bobcat	**-0.901 (0.0095)**	**-0.927 (0.0079)**	-0.306 (0.501)	-0.505 (0.255)	**-0.703 (0.0897)**

Statistical relationships are indicated in parentheses. All categories were calculated from camera and track data combined, with the exception of coyote and domestic canine, which were calculated from camera data only.

Table 6. Spearman rank correlation coefficients for underpass predictor variables and relative frequency of human activities at the underpass sites. Statistical relationships are indicated in parentheses.

Human Activity	Length	Width	Height	Openness
Full-Sized Vehicle	0.108 (0.8222)	-0.357 (0.4444)	-0.288 (0.5286)	-0.214 (0.6615)
Off-Highway Vehicle	0.400 (0.3730)	-0.613 (0.1579)	-0.345 (0.4444)	-0.595 (0.1698)
Humans on Foot	0.108 (0.8222)	0.000 (1.000)	0.288 (0.5286)	0.250 (0.5948)
Total Human	-0.054 (0.9190)	0.000 (1.000)	0.198 (0.6667)	0.286 (0.5560)

Table 7. Mann-Whitney U values for wildlife and human relative frequencies at sites deemed "good" versus "compromised" on the basis of human activity and habitat quality.

	Small-bodied mammals	Medium-bodied mammals	Canid	Bobcat	All wildlife	Full sized vehicles	Off-highway vehicles	Humans on foot	Total Human
Habitat Quality									
Median: Good	0.3588	0.2825	0.0802	0.0157	0.7375	0.0334	0.0489	0.1338	0.2825
Median: Comp.	0.5726	0.5560	0.4760	0.0057	0.6556	0.2320	0.1162	0.2600	0.5560
U	0.538	2.778	1.960	0.368	0.040	3.247	1.960	1.960	2.778
P-value	0.4630	0.0960	0.1620	0.5440	0.8410	0.0720	0.1620	0.1620	0.0960
Human Activity									
Median: Good	0.2843	0.2825	0.0791	0.0157	0.6556				
Median: Comp.	0.5916	2.9375	0.6429	0.0030	1.2857				
U	3.738	9.000	9.000	0.550	5.440				
P-value	0.0530	0.0027	0.0027	0.4580	0.0200				

Discussion

A wide variety of wildlife utilize the underpass structures included in this study, confirming their value in allowing wildlife movement. For species with small home ranges, such as ground squirrels, desert cottontails, and black-tailed jackrabbits,

underpasses likely provide convenient access to foraging habitat on either side of the highway. Small rodent species and reptiles may reside within or near the underpass structures. Habitat within the corridor can be important for sustaining small-bodied and less motile corridor-dwelling species (Barrows et al. 2011), and such species were found both near and within the underpasses. Large-bodied mammal species, such as coyotes and bobcats, are utilizing the underpasses as linkages between larger territories and home ranges.

There was a positive association between the rate of occurrence of medium-bodied mammals and ground squirrel species with underpass length, and a negative association for these two groups with underpass openness ratios. These same relationships have been found elsewhere for small and medium-bodied mammals. Rodriguez et al. (1996) hypothesized that this preference exists because prey species are better secured from being ambushed by predatory species in structures with these attributes. I also found a weak negative trend between bobcat use and underpass length (Table 5). Ng et al. (2004) found these same relationships between bobcats, medium-bodied mammals and underpass length and openness ratios at their study sites near Los Angeles, California.

Data collected from the cameras allowed for accurate distinction between coyote and domestic canine occurrences. Therefore only those records were used when the relationships for those two species were analyzed. However, detection of coyotes and canines is biased towards track bed methods because camera response times are often inadequate to capture their fast movements (Ford et al. 2009). Indeed, combining track

and camera data for canid species (coyote, gray fox, and domestic canine) resulted in almost three times as many detections (n = 256) than camera data alone (coyote n = 19, gray fox n = 3, domestic canine n = 67). Coyote frequency was negatively correlated with underpass width. These data disagree with expected results, such as those reported by Clevenger and Waltho (2005) who found that carnivore species, such as wolves (*Canis lupus*), tend to prefer structures that are wide and short. Because of these inconsistent results, additional monitoring is needed to better understand these relationships, and to determine whether these trends are a function of differences in animal behavior in desert versus more vegetated habitats.

For sites categorized as "good" versus "compromised" on the basis of habitat quality and proximity to human developments, the rates of occurrence for medium-bodied mammals were found to be higher in the "compromised" sites. This is most likely due to the availability of water and food resources near residential communities with "compromised" habitat, which might attract several of the species included in the medium-bodied mammal category, namely domestic felines, skunks, and raccoons. Another possibility is that, being habitat generalists, these species do not have strict habitat requirements and were therefore less affected by the habitat quality near residential areas. No differences were detected for large bodied mammals. Large bodied mammals are likely to only be utilizing the areas surrounding the underpass structures as move-through habitat and are less likely to be affected by habitat quality if adequate cover is present. As expected, the rates of occurrence for full-sized vehicles and total

human activity were found to be higher in the "compromised" sites, as these are nearest to human habitation and therefore offer more convenient access.

For sites categorized as "good" versus "compromised" on the basis of human activity, the rates of occurrence of small-bodied mammals, medium-bodied mammals, canids, and all wildlife analyzed together (excluding canids) were higher in sites categorized as "compromised". This may indicate a willingness for these wildlife groups to use areas near human activity, not necessarily an attraction to the human activity itself. Although bobcats were negatively associated with both full-sized and off-highway vehicle usage at the underpasses, no difference was detected between the rates of bobcat usage for sites deemed "good" versus "compromised" on the basis of total human activity (Table 7). It has been suggested that bobcats residing near fragmented areas adjust their behavior to spatially and temporally avoid human activities (Tigas et al. 2002); thus the absence of a significant difference is most likely due to the tendency for bobcats to utilize the underpass structures during times when human activity is least likely (Fig. 10).

Mule deer and mountain lions were only documented at one underpass location, Dry Morongo. Of the underpasses included in this study, Dry Morongo has the shortest length (Table 1) and the largest single chamber width (Fig. 6e), which both contribute to its relatively high openness ratio of 11.40. Numerous studies have reported that ungulate species are particularly influenced by structural characteristics of underpasses (Reed et al. 1975, Foster and Humphrey 1995, Dodd et al. 2007). Preferred underpass dimensions combined with close proximity to the mountain ranges on either side of the structure may combine to make this a suitable crossing structure for ungulates. However, desert bighorn

sheep (*Ovis canadensis nelsoni*), which are known to inhabit the mountain ranges on either side of State Route-62 (Penrod et al. 2005a), were never found approaching or utilizing the underpass. This may be due to the high relative frequency of human activity and domestic canines near and through this underpass structure. Previous underpass studies have found that human activity has a negative impact on underpass use by wildlife (Clevenger and Waltho 2005). Mountain lions, however, show little aversion to human activities (Beier 1995), and previous studies found no correlation between human and cougar use of underpass structures (Gloyne and Clevenger 2001). A positive correlation was found between cougars, mule deer and white-tailed deer, the latter being the primary food source of the lions (Gloyne and Clevenger 2001).

Whitewater canyon was delineated as a primary least cost corridor, or best potential route, for mountain lions by a landscape permeability analysis (Penrod et al. 2005b). Although mountain lions have been observed traversing the canyon (Frazier Haney, Whitewater Preserve, *pers. comm.*) no mountain lions were documented near the underpass opening. Bobcats were recorded on several occasions as having utilized the underpass, indicating no aversion to the underpass dimensions or surrounding landscape characteristics and therefore demonstrating the potential suitability of this structure for use by other large carnivore species. As Whitewater underpass is the widest of the underpass structures included in this study (Table 1) and includes eight chambers, it was difficult to monitor the underpass in its entirety.

Mule deer were documented at Cottonwood canyon (n = 2) and are known to inhabit the Snow Creek area south of I-10 but were not detected at any of the underpass

sites along I-10. This may indicate a reluctance to traverse the desert matrix between the canyon and highway resulting in a low likelihood for this species to cross between the mountain ranges, or utilize the underpasses.

Wildlife road kill occurrences were infrequently observed upon I-10. Although the rate of successful wildlife crossings directly upon the highway is unknown, the camera and track data I collected suggest that individuals of most of the wildlife species known to occur in this area have utilized the underpass structures. Exclusion fencing runs parallel to the highway within the study area; however, lack of maintenance has rendered it inadequate and opportunities exist for wildlife to enter upon the highway through gaps in the fencing. Wildlife road mortality upon SR-62 was more frequent than that experienced on I-10. Lower average annual daily traffic volumes compared to I-10 (http://traffic-counts.dot.ca.gov/) and gaps in the fencing both may contribute to wildlife approaching the roadway more frequently along SR-62. Medium-bodied wildlife were the most frequently observed category of road-killed wildlife; however, this may be due to the difficulty of detecting small-bodied animals, such as lizards and mice, that have been killed upon the roadway. Interestingly, the highest road kill occurrences were recorded upon the shoulders of highway transitions, such as the transition from the I-10 to SR-62, and Highway 111 to I-10, an observation which has recently been noted by colleagues on other highways systems (Lisa Lyren, USGS, *pers. comm.*); the cause of this pattern is still under consideration.

Recommendations

San Bernardino - San Jacinto Mountain Range Linkage

I recommend that monitoring of the underpass structures continue for as long as possible in order to capture the range of variation between years caused by the dynamic wildlife-human-land use interactions in this area, and to minimize the potential for spurious results (Clevenger and Waltho 2003). Additionally, these results only account for the frequency of occurrence near the underpass structures and canyons monitored, and do not provide the data necessary to address whether these structures are effective- that is, whether gene flow is enabled. Genetic analysis of populations on both sides of the barrier should be undertaken to determine whether there is genetic variability and whether heterozygosity among populations is being maintained (Riley et al. 2006). Additional sampling should be implemented within the matrix surrounding the underpass structures to determine if certain species are avoiding the road or whether wildlife species decrease in abundance as the highway is approached, a phenomenon known as a filter effect. Special attention should be extended to determine wildlife behavioral responses to alternative energy projects near the corridor and whether these projects are impacting or impeding movement through the landscape matrix, especially by wide ranging species.

I found a broad range of wildlife utilizing the underpass structures along Interstate-10 and Highway-111 during the 13-month monitoring period. However certain underpasses were used more frequently by certain species. Although bobcats were found north of the I-10 within Cottonwood canyon (n = 10), only Stubbe West underpass facilitated bobcat crossings (Table 3) despite the close proximity of Stubbe East and

Cottonwood underpasses. The lowest rate of total human occurrences of these three underpasses was at Stubbe West underpass. Efforts should be taken to reduce access to Stubbe West by full-sized and off-highway vehicles, perhaps by placement of large boulders near the entrance of the structure. Also, this structure contains an atrium that allows natural sunlight and water to enter the passage; however refuse has accumulated within the structure inhibiting growth of vegetation beneath the atrium. Clearance of the refuse is recommended to allow growth of native vegetation within the structure. The combination of both of these actions may improve the condition of this underpass and further influence its use by native wildlife species.

San Bernardino - Little San Bernardino Mountain Range Linkage

The Bureau of Land Management has protected 3-km of land on both sides of Dry Morongo underpass, which secures connectivity between the mountain ranges for bighorn sheep movement (Penrod et al. 2005a). Although land south the Dry Morongo underpass was delineated as a best potential route for bighorn sheep movement by a landscape permeability analysis (Penrod et al 2005a), no bighorn sheep were found approaching or utilizing Dry Morongo underpass during the duration of monitoring. Human recreational activities may inhibit wildlife use and degrade habitat quality. Regulators may want to reduce off-highway vehicle access to Dry Morongo underpass to eliminate habitat disturbance and wildlife avoidance of these areas (see also Penrod et al. 2005a). Mountain lions, bobcats, and coyotes were documented as having utilized Dry Morongo underpass during the monitoring period, but only two mule deer were recorded at the underpass opening and no bighorn sheep, suggesting avoidance by ungulates.

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