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AUTHOR: Kelcey Stricker

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Dr. William Kristan THESIS COMMITTEE CHAIR	Bill Krist SIGNATURE	5/5/15 DATE
Dr. Tracey Brown THESIS COMMITTEE MEMBER	SIGNATURE	5/5/15 DATE
Dr. Thomas Spady THESIS COMMITTEE MEMBER	Thomas Spady SIGNATURE	5/5/15 DATE

The Effect of Interstate 15 on Mammalian Communities in Southern California's Conserved Lands

Kelcey Stricker

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Abstract

Human induced fragmentation of habitat through urbanization and road construction blocks routes of immigration and emigration for wildlife and can interrupt metapopulation dynamics, leading to localized extinction events. To determine the effect of the I-15 highway on the mammalian mesopredator community composition in a protected wildlife corridor, the Santa Ana Palomar Mountains Linkage (SAPML), 32 camera stations (e.g. camera traps) were placed at varying distances from the road from 2012-2013. Cameras were also placed at the entrances to culverts that run under the I-15 in an attempt to capture mammals that may pass under the road. Out of 1043 sampling days, 765 video clips were captured of which 232 recorded positive detections of the focal species. While distance from road and noise pollution from traffic were predicted to have the greatest effects on mammalian community composition, habitat type was found to be the strongest predictor of detection of bobcat (*Lynx rufus*), coyote (*Canis latrans*), and gray fox (*Urocyon cinereoargenteus*). There were an insufficient number of video clips recorded of mammalian wildlife using the culverts, limiting the ability to conduct a rigorous statistical analysis on the effectiveness of culverts as wildlife passages in the SAPML. However, anecdotal evidence suggests that at least some individuals of coyote, bobcat, gray fox, and raccoon (*Procyon lotor*) are successfully moving through these culverts.

Introduction

Mammalian species move across the landscape for a variety of reasons including migration, foraging, and dispersal. Movement due to migration and foraging can have a positive effect on the population by decreasing predation pressure and preventing population crashes. Movement due to dispersal decreases intra-specific competition for resources, increases genetic diversity and prevents inbreeding depression (Clutton-Brock 1989, Matthysen 2005, Clutton-Brock and Lukas

2012). Dispersal is important because it can help sustain metapopulations. Metapopulations are collections of subpopulations that occupy a general area on the landscape and are connected by movements between the subpopulations (Hanski and Gilpin 1991). Further, species movements are affected by biotic and abiotic effects such as fluctuations in the availability of food resources and refugium; populations are continually moving across landscapes as they track resources from place to place. When these natural movement patterns and ecological processes are interrupted by anthropogenic land use change, such as urbanization and road construction, populations can become unstable and even experience localized extinction (Hanski et al. 1996, Hanski 1998, Debinski and Holt 2000, Crooks 2002, Riley et al. 2003, Riley et al. 2006).

Landscape-level conservation planning must consider how much habitat is conserved, as well as the best configuration and design of a reserve to accommodate the diverse ecological needs of resident biodiversity (Noss et al. 1995). Planning must also take into account the importance of metapopulations. Provided colonization events are equal to or greater than extinction events across the metapopulation, the system is entirely self-sustaining (Hanski et al. 1996, Hanski 1998). Thus, localized extinction of a subpopulation in a naturally functioning system is not necessarily a detriment to the species as a whole. However, human-induced fragmentation of habitat through urbanization and road construction blocks routes of colonization for subpopulations. These interruptions stymie genetic exchange between subpopulations, and can facilitate localized extinction events; this makes it difficult for a metapopulation to continue to function (Hanski 1998, Epps et al. 2005, Noss et al. 2006, Riley et al. 2006). Human induced habitat fragmentation as the result of urbanization and road construction is one of the greatest challenges in contemporary biological conservation (Noss et al. 1995, McKinney 2002, Crooks and Sanjayan 2006). The loss of landscape-level movement leads to loss of metapopulation function, including increased levels of inbreeding, lowered genetic diversity, and overall lowered fitness (Frankham 1995, Lacy 1997, Jaeger et al. 2005, Epps et al. 2005, Riley et al. 2006, Hanski et al. 1996). The modern challenge for conservation planning is to provide sufficient habitat protection, but also facilitate metapopulation dynamics.

In southern California, human induced fragmentation through urbanization and road construction has caused changes in population-level genetics and spatial distribution for ecologically important mesopredators such as bobcat and coyote (Riley et al. 2003, Riley et al. 2006). Riley et al. (2006) found that populations of bobcats and coyotes have been isolated by construction of the Ventura freeway near Los Angeles. Riley et al. (2006) also found indications that the isolated populations are genetically diverging from the original populations. While dispersal still occurs, at a reduced rate, the actual genetic exchange rate is less than 0.5% per generation, which is likely not an appropriate level for long-term population viability (Riley et al. 2006). In addition, "territory pileup" near the road's edge is an increased stressor (due to increased antagonistic intraspecific interactions) that can reduce reproductive opportunities for individuals that manage to cross the road (Riley et al. 2006).

The influence that roads have on species like bobcat and coyote is complicated and considerable research has attempted to understand how roads and urban areas affect them. For example, researchers have observed changes in the home-range size of coyote and bobcat, suggesting that fragmentation and urban edge were having an influence on species as opposed to direct effects from the road (Riley et al. 2003). Further, female adult bobcats are not association with urban edge, while coyotes, adult male bobcats, and juvenile female bobcats had home ranges that were positively associated with urban edge (Crooks et al. 2003). Understanding these relationships is critical when designing a reserve system and ensuring that a conservation plan will successfully protect target species.

Finally, conservation biologists must not only consider the implications that habitat fragmentation and isolation have on the movement of species, but also how this ultimately affects overall population health and genetic viability. Throughout the literature, researchers have documented how the interruption of movement across a landscape and spatial changes in home-range distribution will often interrupt genetic exchange, to the detriment of the population (Epps et al. 2005, Frankham et al. 2006, Riley et al. 2006). Riley et al. (2006) demonstrated that when populations experience increased genetic homogeneity (in historically heterogeneous populations), there is an associated decrease in overall fitness (Hedrick and Kalinowski 2000). Therefore, the construction of a barrier, such as a freeway, is expected to reduce genetic exchange between subpopulations, which is likely to reduce fitness. Facilitating the movement of individuals across a landscape is considered essential to the survival of a species (Crooks and Sanjayan 2006, Bunn et al. 2007). As a result, understanding and improving wildlife movement affected by existing barriers is a growing concern in land use planning and conservation biology.

Urban Effects

Habitat loss and degradation is the leading cause for endangerment and extinction in the United States (McKinney 2002, Bunn et al. 2007). Conversion of an ecosystem to an urban area (e.g. urbanization) creates impermeable barriers and has consistent and intense negative effects on wildlife movement (Riley et al. 2003, Borchert et al. 2008, Nogeire 2012). The human activities associated with urbanization can lead to degradation of the surrounding (un-urbanized) habitat, particularly when accompanied by artificial noise and light output (Longcore and Rich 2004). Identifying strategies for reducing these effects are critical to successful biodiversity conservation programs in urbanized areas. However, an effective program with avoidance, minimization, or mitigation strategies requires an understanding of the kinds of anthropogenic effects that emanate from the urban area, and how far those effects intrude into the natural landscape.

Urban areas and roads often create noise levels that are significantly higher than natural, ambient conditions due to a myriad of factors including sounds from vehicles, industrial activities, and other human actions (Nordt and Klenke 2013). High nighttime lighting levels are also associated with urban areas, common in parking lots, roads, homes, and commercial buildings, raising the lighting levels significantly above natural ambient conditions (Nordt and Kelnke 2013, Bennie et al. 2014). This "light pollution" can alter the behavior of animals that use natural lighting cues—moonlight, sunrise, sunset—to guide their daily activities (Muheim et al. 2009, Prugh and Golden 2014). However, not all species are negatively affected by our urban footprint. Species such as coyote can benefit from urbanization through the additional food input of trash; domestic animals can also serve as a source of food for some predators. Coyotes in urban areas are also much more likely to be active in the evenings and nighttime than those in natural habitat (Tigas et al. 2002, Riley et al. 2003, Darrow and Shivik 2009). The artificial noise and light pollution of urbanized areas is not just from homes, shopping malls, and sports parks, it is also produced by the variety of roads and highways that are constructed to access these urban features.

The conversion of an ecosystem into roads or urban areas can create fragmented habitat, resulting in matrix habitat that is composed of varying levels of degraded land with variable levels of noise and light pollution (McKinney 2002, Crooks and Sanjayan 2006, Coffin 2007). Wide ranging and highly mobile species are most sensitive to fragmentation and most likely to experience extirpation from the isolated habitat patches (Epps et al. 2005, Jaeger et al. 2005, Riley et al. 2006). Generally, mammalian species that require large territories or that must periodically move across the landscape to complete their life history can be negatively affected by human-induced fragmentation of their habitat (Crooks and Sanjayan 2006). In many systems these species are large mammals, particularly carnivores (Crooks 2002, Riley et al. 2006, Riley 2006). Carnivores require a large prey base to meet their energetic needs therefore they have larger home ranges by necessity (Dickson and Beier 2002, Feldhammer et al. 2003). Carnivores such as bobcat have home ranges highly dependent on the density of prey and their own physiology (i.e. gestating females require larger home ranges because a larger prey base is required to meet energetic needs). These constraints can often result in a relatively low density of individuals across a contiguous landscape (Feldhamer et al. 2003, Ferguson et al. 2009).

As mentioned above, some large and medium sized mammals can benefit from the effects of fragmentation. Fragmentation (as a result of urbanization) can augment food sources for omnivores such as coyote and raccoon by enabling access to trash and domestic animals (Gese et al. 1996, Hidalgo-Mihart et al. 2004, Prange and Gehrt 2004, Atwood et al. 2007). Additionally, fragmentation that results in extirpation of top predators (e.g. mountain lions) can often have a positive effect on the mesopredator community by relieving predation pressure (Crooks and Soule 1999). Mesopredators (meso=”middle”) are those species which are typically not considered “top predators" in their ecosystem, but which do exert predation pressure on lower trophic levels (Crooks and Soule 1999, Ritchie and Johnson 2009, Roemer et al. 2009). These species are a mix of carnivores and omnivores, while top predators are often carnivores. Carnivores (in the ecological sense, but not the taxonomic sense) and mesopredators are the classification of the focal species in this study because they encompass the groups of mammalian predators that occupy key places in the southern California ecosystem and the study area. They also have variable responses to urbanization and urban intensity (Feldhammer et al. 2003, Ordinena et al. 2010).

Areas that lack top predators often have a higher than expected number of mesopredators (Crooks and Soule 1999). In Crooks and Soule (1999), isolated canyons where coyote were removed had an overabundance of mesopredators (e.g. raccoons). In these areas, where this species is the top predator, coyote presence or absence was an important predictor of the total number of mesopredators, the presence of domestic cats, and the presence of opossum and raccoons (Crooks and Soule 1999).

The Road Effect Zone

Transportation corridors in particular represent a unique type of land use change that has specific effects on native biodiversity. Indeed, one of the most prevalent types of habitat fragmentation is road construction. While not all areas where roads are constructed are considered urbanized areas, the vast network of roads, freeways, and highways have created a complex web of interconnected infrastructure that is used to transport goods and people between urbanized, agrarian, and other human-altered landscapes (Forman 2000). Roads remove habitat, degrade surrounding habitat, are a source of mortality for species moving through the area, and may discourage species' movements by creating matrix habitat that animals will not cross (Forman et al. 2003). The fragmenting and disruption effects of roads on metapopulations and wildlife communities can be predicted by understanding what is known about the effects of habitat fragmentation in general and urbanization in particular (Forman 2000, Forman and Deblinger 2000, Coffin 2007).

Within the United States, urbanization and its accompanying road construction is one of the greatest threats to habitat conservation efforts (McKinney 2002, Forman et al. 2003). An estimate made nearly two decades ago by Forman and Alexander (1998) puts U.S. road density at 1.2 km/km^2, or roughly 1% of the total surface area of the U.S. While this national estimate is alarming, roads are not evenly distributed across the U.S., and areas with vast transportation infrastructure like Southern California have significantly higher percentages of land subsumed under pavement.

Roads affect wildlife populations by removing habitat directly, fragmenting the habitat that remains (Forman et al. 2003), and by introducing a source of mortality to wildlife attempting to cross those roads (Forman et al. 2003, Coffin 2007, Smith-Patten and Patten 2008). Beyond the physical footprint of the road, noise and light pollution from the automobiles can extend into adjacent areas (Forman and Deblinger 2000, Forman et al. 2003, Delgado et. al. 2007). These pollutants can elicit behavioral changes in carnivores, mesopredators, and other wildlife that may affect their survivability (Grigione and Mrykalo 2004, Longcore and Rich 2004, Rich and Longcore 2005, Darrow and Shivik 2009). Specifically, artificial noise has been known to alter the behaviors of carnivores and mesopredators, including coyote, such that territories are altered or abandoned, and less time is spent foraging (Gese et al. 1989, Larkin et al. 1996). The extent to which pollutants produced by automobiles can affect an ecosystem is not well understood, but is of concern in habitats where roads are affecting and fragmenting landscapes (Forman et al. 2003, Crooks and Sanjayan 2006). This area adjacent to roads that changes ecologically due to the presence of the road has been identified as the "Road Effect Zone", and is a major consideration in fragmentation and conservation planning (Forman and Alexander 1998, Forman and Deblinger 2000, Forman et al. 2003).

The size of the road effect zone can vary depending on a variety of abiotic and biotic factors (Forman and Alexander 1998, Forman and Deblinger 2000, Forman et al. 2003, Delgado et al. 2007). Studies of the size of road effect zones have identified at least nine distinct effects that extend more than 100 meters from the edge of the road, including fragmentation, artificial lighting, and noise (Forman and Deblinger 2000). Two of the of the nine road effect zone factors which have the greatest measured effect on wildlife included direct mortality from car-wildlife collisions, and the avoidance of road areas by wildlife due to noise output from traffic (Forman and Deblinger 2000, Forman et al. 2003, Riley et al. 2003, Coffin 2007). Roadkill depletes surrounding populations through increasing mortality rates of individuals attempting to cross a road, or who have approached the road for other reasons (e.g. scavenging). This reduction in population can be difficult to measure and often varies by species (Antworth 2005, Coffin 2007, Smith-Patten and Patten 2008).

The type of habitat (density and type of vegetation, plant species composition, topography) a road crosses, along with the size of the road and the volume of traffic it carries, are three main factors which can predict the level of light and noise pollution observed in the surrounding ecosystem

(Forman and Deblinger 2000, Forman et al. 2003). Carnivores and mesopredators are typically expected to avoid roadsides due to elevated noise levels (Beier 1995, Lovallo and Anderson 1996). However, the distance of spillover of noise pollution into the road effect zone can vary depending on a variety of biotic and abiotic factors (Delgado 2007). For example, density and type of vegetation surrounding the road can affect the distance that traffic light and noise will travel into the ecosystem (Forman and Deblinger 2000, Forman et al. 2003). Topography can also influence the distance sound and light will travel, because hills and berms dampen sound and block light at a shorter distance from the road's edge than flat lands and meadows (Forman and Deblinger 2000, Forman et al. 2003).

More recent work has addressed the positive effects of the road effect zone on certain species, especially those that are natural scavengers. Native scavengers can benefit from the presence of roads via an increased abundance of road kill (DeVault et al. 2003, Kristan et al. 2004). The Common Raven (*Corvus corax*) is often associated with roadsides and can have increased fledgling success based on the presence of road-kill (Kristan 2004). Multiple species of scavengers have been shown to be attracted to the increase in carrion along roadsides, including coyote, gray fox, and raccoon (Antworth et al. 2005, DeVault et al. 2003).

Despite the potential benefits for some species, roads are associated with a significant amount of direct mortality (road-kill) (Riley et al. 2003, Coffin 2007, Smith-Patten and Patten 2008). The relative repellent and attractive qualities of the road effect zone will vary from species to species and from place to place, largely dependent on confounding factors such as artificial noise, light, and carrion, (Markovchick-Nicholls et al. 2007, Feldhammer et al. 2003). Similarly, there is most likely variability in road effects associated with different types and qualities of habitat. A road that is built in an area that is already heavily fragmented and urbanized will have a different effect on biodiversity than one that is built in previously undisturbed vegetation. Conservation strategies therefore have a monumental task: they must take into account all of these diverse factors when creating a plan for protecting species and ecosystems.

Road Permeability

While roads can present a significant barrier to wildlife movement, a number of studies have examined how species have successfully avoided road hazards (Dodd et al. 2004, Ng et al. 2004, Serronha et al. 2013). Wildlife overpasses constructed for the purposes of moving wildlife over roads have had some success (Forman et al. 2003, Clevenger & Waltho 2005, Forman et al. 2003, Mata et al. 2008). However, many conservation strategies are starting to focus on the opportunistic use of existing road features such as drainage culverts as a tool for planning; wildlife have been documented using these features to cross underneath roads and successfully avoid or minimize mortality (Clevenger et al. 2001, Taylor & Goldingay 2003, Ng et al. 2004, Ascensao & Mira 2006, Grilo et al. 2008, Serroha et al. 2013). In Taylor & Goldingay (2003), over 1202 trips through nine culverts over a period of seven days were recorded through track stations. Clevenger et al. (2001) found that structural components of culverts—material, size of opening, length of culvert, type of habitat near entrance—had an influence over the type of species that were likely to cross through them. Ascensao and Mira (2006) confirmed that vegetation near the entrance of a culvert affected which species was likely to use that passage; they also suggested that using a variety of culvert sizes and types was the best strategy to ameliorate the negative effects of roads and habitat fragmentation.

A number of studies have been conducted to determine the relative contribution such structures make to overall habitat connectivity (Clevenger et al. 2001, Taylor & Goldingay 2003, Ng et al. 2004, Ascensao & Mira 2006, Grilo et al. 2008, Serroha et al. 2013). While, theoretically, many species could safely travel through underpasses and culverts, there is high variability in the overall success rate of crossings and the type of species are documented utilizing these under-crossings (Clevenger et al. 2001, Tigas et al. 2002, Clevenger and Waltho 2005, Ascensao and Mira 2006). Some species were more likely to risk crossing over a dangerous road than they were to use a culvert. For example, Tigas et al. (2002) found that, while bobcats and coyotes would occasionally use the culverts in Los Angeles, California, they were more likely to directly cross over the roads themselves. Unfortunately, it is not always clear why some under-crossings are more successful at facilitating wildlife movement than others, although several studies have attempted to answer this question.

The factors that are known to influence the variability in utilization rates of culverts and underpasses include: the road-effect zone, species life history, antagonistic inter-and intra-specific interactions (including human avoidance), topography and vegetation surrounding the openings, and size of underpass or culvert (Clevenger et al. 2001, Taylor & Goldingay 2003, Ng et al. 2004, Ascensao & Mira 2006, Grilo et al. 2008, Serroha et al. 2013). Many studies and conservation plans have relied on pre-existing drainage culverts and underpasses when assessing wildlife movement across a landscape (Clevenger and Waltho 2005, Clevenger et al. 2006, Ascensao and Mira 2006), though most of these structures were never designed with wildlife movement in mind. However the benefits of these structures should not be understated. The contribution of culverts and underpasses to habitat permeability is not insignificant and many species that would normally be expected to avoid roads have been known to cross or attempt to cross them, especially if the roads occur in their core habitat (Dickson and Beier 2002, Tigas et al. 2002).

The way an undercrossing is designed can also significantly influence wildlife use and movement. In fact, the Openness Index (OI) is considered one of the more significant factors found to affect wildlife use of culverts. Originally designed as a surrogate for ambient light available within a culvert (and thus likelihood of usage by wildlife), the width to length ratio of the structure has been a relatively consistent factor in predicting the type of species to use a culvert. The following OI formula is from Mata et al. (2008):

$$OI = (w)(h)/(l)$$

where w is the culvert entrance width, h is culvert entrance height, and l is length of culvert passage (m).

An OI greater than 0.3 is associated with presence of carnivores and mesopredators (ie. coyote), while an OI of less than 0.1 is associated with presence of reptiles and small mammals (Mata et al. 2008; Table 1). An OI of 0.3 is typically associated with an approximately two-lane highway or road with a culvert diameter of six feet (2.3 meters), or box culvert of width/height dimensions of two feet by three feet. Per the U.S. Department of Transportation Federal Highway Administration, lane widths for rural and urban highways are equal to 12 feet (3.6 meters) per lane, which equates to an OI value of 0.3.

This type of culvert would generally allow a clear view of the opening on the other side and would include a large amount of ambient lighting; both of these factors presumably encourage crossings by larger mammals such as coyotes.

The Santa Ana Palomar Mountains Linkage

In southern California, rapid population growth and urbanization has resulted in extensive fragmentation from road construction and land use change with conservation planning focused on protecting the remaining patches of native habitat as well as habitat linkages between them (MSCP 1997, MSHCP 2003, Lacher and Wilkerson 2014). Habitat linkages, which allow wildlife to move between isolated habitat patches, have become a core concept in conservation planning as a way to relieve the isolation of habitat fragmentation (Crooks and Sanjayan 2006, Hilty et al. 2006). These habitat linkages are thought to mitigate some of the potential negative effects of habitat fragmentation caused by land-use change by allowing animals to move between patches of protected habitat and increase the effective total size of that habitat.

In 2000, the Southcoast Wildlands Missing Linkages Project organized a group of scientists and land managers for the purpose of identifying the key threatened habitat linkages in southern California (Penrod et al. 2001). The resulting report identified 15 key habitat linkages necessary for preserving connectivity in the region. All linkages identified had at least one anthropogenic barrier, which limited (or potentially limited) its functionality (Penrod et al. 2001). Of these affected linkages, the Santa Ana-Palomar Mountains Linkage area (SAPML) was identified as the last inland-to-coastal linkage in southern California (Figure 1) (Luke et al. 2004). This linkage is also considered essential to the persistence of mountain lions (*Puma concolor*) in the Santa Ana Mountains (Beier 1995, Beier et al. 2006).

The footprint of the SAPML runs West to East and includes conserved habitat from the coast (Fallbrook Navel Weapons Base and Marine Corps Base Camp Pendleton) to the inland areas (Santa Margarita Ecological Reserve, Pechanga Indian Reservation, and Agua Tibia Wilderness Areas). The SAPML also straddles the San Diego and Riverside County lines. The narrowest portion of the linkage is completely bisected by the I-15 (Figure 1). Where it crosses through the SAPML, the I-15 consists of 5 lanes in each direction (North/South), with a solid median of cement or wood and metal guardrail and a speed limit of 70 miles per hour (mph), making it one of the largest paved roads in southern California. The I-15 had an Average Annual Daily Traffic (AADT) load of 129,000 cars in 2008 at the San Diego-Riverside County line (Cal-Trans 2008). This segment of highway is ranked as 309 out of the 328 top congested transportation corridors in the United States per a 2011 Texas A&M study of traffic congestion (Eisele et al. 2011). This traffic load is 3.7 times higher than other large freeways which cross through protected habitat such as the Trans-Canada highway which receives a peak traffic load of 35,000 vehicles a day on a total of four lanes (two in each direction)(Clevenger et al. 2001).

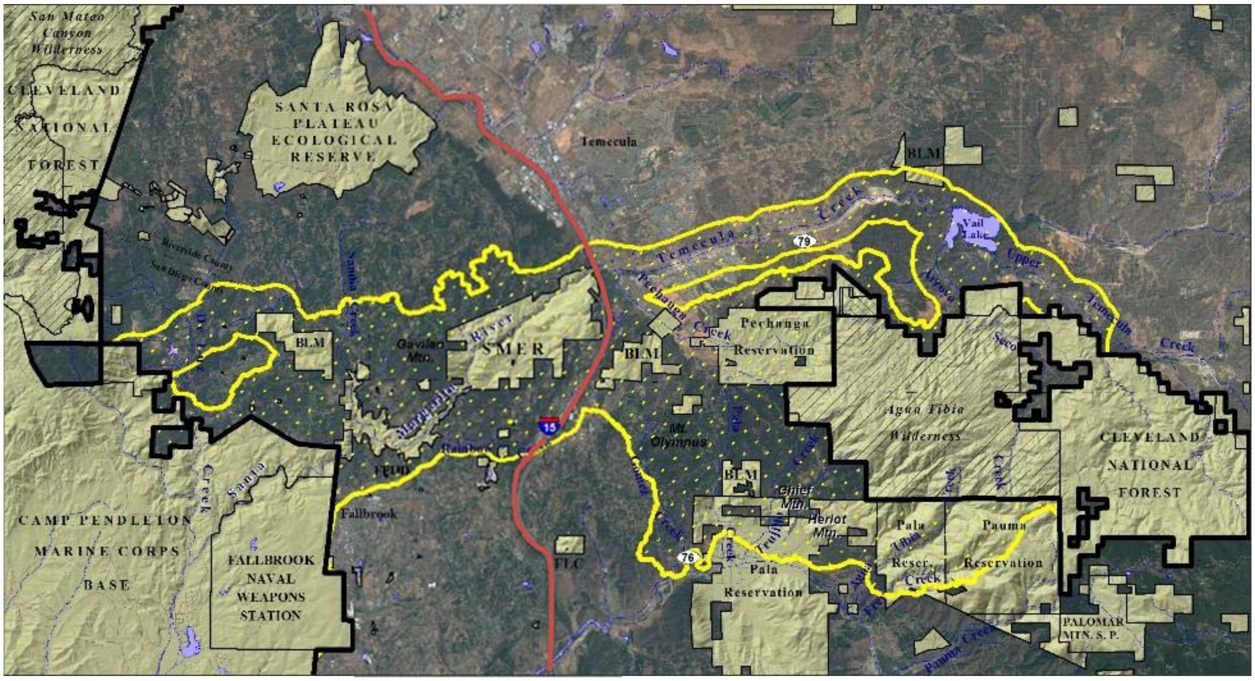

Figure 1. Figure taken from Luke et al. (2004) showing the Santa Ana Palomar Mountain Linkage (SAPML) in western Riverside County, California. Yellow stippled area is the SAPML as modeled by Luke et al. (2004). Conserved lands and open space are shown in tan. The I-15 freeway can be seen running through the narrowest portion of the SAPML in red.

Purpose

Currently, there are no overpasses available for wildlife over I-15 in the study area. However, there are many drainage culverts and a large riparian underpass that potentially could provide safe crossings for wildlife. Use of these features by wildlife in the SAPML is unknown, and existing studies on culverts and underpasses have addressed the effect of roads much smaller than the I-15 (Taylor and Goldingay 2003, Ascensao and Mira 2007, Grilo et al. 2008). As a result, the culverts and underpasses that have been studied contain wide openings and short distances when compared with those on I-15.

The purpose of this study was to begin to examine the effect of the I-15 on the functionality of the SAPML by examining how the native carnivore and mesopredator community is responding to the presence of such a large road. To address this question, several factors that may indicate the I-15 is affecting the functionality of the SAPML were examined. These included which species were present in the road effect zones and at various distances from the road's edge. Other factors studied, which had the potential to affect these species' use of the road's edge, included: habitat type, ambient noise level, temperature, moon phase, and presence of other individuals.

Examining the extent and effect of the road effect zone in a particular habitat type is an essential tool in conservation planning. How a road affects the distribution and abundance of wildlife across a landscape is the first step towards understanding how those species interact with the built environment. By determining the relative functionality of the SAPML on facilitating movement of native populations of carnivores and mesopredators, effective conservation measures can be developed to further reduce any potential isolating effect of the I-15.

Methods

Selection of Focal Species

In the southern California ecoregion, carnivores and mesopredators play an essential role in maintaining the ecological community composition by exerting top-down controls on the trophic system (Miller et al. 2001, Feldhamer et al. 2003, Beier et al. 2006). In addition, their relatively low reproductive rates, and longer life cycles make them more vulnerable to landscape fragmentation (Mills et al. 1993, Miller et al. 2001, Tigas et al. 2002, Noss et al. 2006, Riley 2006).

Because of their important role in maintaining the native southern California ecosystems and their relative sensitivity to fragmentation, native carnivores and mesopredators were selected as the focal species for this study. Further, they have a range of responses and sensitivities to noise, light, and urbanization (Feldhammer et al. 2003, Ordinena et al. 2010) These focal species include: coyote (*Canis latrans*), bobcat (*Lynx rufus*), striped skunk (*Mephitis mephitis*), gray fox (*Urocyon cinereoargenteus*), opossum (*Didelphis virginiana*), mountain lion (*Puma concolor*), ringtail (*Bassariscus astutus*) , and raccoon (*Procyon lotor*). Additional species analyzed include domestic dog (*Canis familiaris*), human (*Homo sapiens*), cottontail rabbit (*Sylvilagus audubonii*), and small mammals (Order: Rodentia); while these species were not the focus of this study, data were collected on them incidentally and additional analyses provided information on the functionality of the SAPML.

Because all data collected were passive in nature, approval from the Institute of Animal Care and Use Committee (IACUC) was not applicable to this project. Additionally, IRB approval was not needed because passive sampling did not require interaction with the people recorded, and no individually identifying data were collected for humans detected in the clips.

Preliminary Data

Remotely-triggered cameras have been successfully used to document animal activity and presence (Heilbrun et al. 2006, Crooks et al. 2008), therefore camera traps were used for this preliminary data collection effort (Lyra-Jorge et al. 2008). The accuracy of species identification is much greater than that of track stations; in addition, stationary cameras often detect species that will actively avoid track stations, providing a better quantification of species presence in the study area (Bellis 2008).

Two previous studies in this area were performed using remotely triggered cameras and the data collected from these studies were used to inform the study design and data collection methods for this research. In 2006, stationary cameras were placed at culvert entrances near the road's edge on the East and West side of the I-15 within the SAPML. This survey was an initial attempt to inventory the wildlife near the road, so culvert entrances were the only areas targeted. Cameras were baited with scent lure (Carman's Canine Call, F&T Fur Harvester's Trading Post, Alpena, Michigan) and captured black and white still images. Over the course of three weeks, over 300 images of animals, primarily carnivores and mesopredators, were detected including raccoon, striped skunk, badger, bobcat, coyote, and grey fox. No mountain lions were detected (Rahn unpublished data, 2006).

An additional data collection effort focused on species present on the Santa Margarita Ecological Reserve property in 2009. Remotely triggered video cameras with scent lure (Carman's Pro's Choice, F&T Fur Harvester's Trading Post, Alpena, Michigan) stations were used in riparian habitat along the Santa Margarita River as well as in upland habitat devoid of riparian vegetation and water resources. After two weeks, mountain lion images were detected along with coyote, but no bobcat, raccoon, opossum, striped skunk, badger and grey fox (Stricker unpublished data).

While both initial study efforts attempted to inventory the mammal community within the SAPML, these efforts were also used to measure the relative effectiveness of different types of cameras by examining the error rates, battery consumption, and clarity of image of each during regular usage; cameras used included Cuddeback Trail Master Pro (Cuddeback, Green Bay, Wisconsin), Bushnell Trail Sentry (Bushnell, Overland Park, Kansas), and WildGame (Wildgame Innovations, Grand Prairie, Texas). In addition, baited versus unbaited camera stations were used to examine the relative image capture rate of each.

The 2009 data collection effort provided additional information outside of the species detections; not all animals detected by the cameras visited the scent lure stations. Mountain lions never visited the scent lure station and coyotes had equal numbers of individuals who visited or did not visit the scent station. Visitation was measured by observing whether the animal approached the scent lure station to investigate (smell, within 30 centimeters or closer) or interact with it (roll in, lick, chew, manipulate).

Sampling Schedule

In order to assess the effects of seasonal and meteorological variations in animal movement, data collection for this study was conducted over three sampling periods: September/October (Fall), January/February (Winter), and May/June (Spring). Due to low wildlife activity in hot temperatures, a summer sampling period was not included in this study (Stricker unpublished data 2009). Data collection commenced in September 2012 and concluded in January 2014.

Site Selection

The study site consists of the length of the I-15 freeway where it bisects the SAPML as well as the contiguous habitat that is not affected by roads to the East and West (Figure 2). Access to the Western contiguous habitat (e.g. the San Diego State University's Santa Margarita Ecological Reserve) was granted for the purpose of this study. Access to the eastern contiguous habitat (e.g. BLM lands, private property, and the Pechanga Indian Reservation) was not granted in time to support this study and data were not collected on those properties.

The majority of the individual camera sites consisted of native habitat with moderate to low disturbance. Habitat types included oak woodland, riparian, chaparral, and disturbed. Habitat was assessed in the field for number and total percent cover of invasive and exotic plant species as well as indicators of human disturbance such as trash, foot paths, and graffiti in a 10x10 meter square area surrounding the camera station. Low disturbance areas were categorized as those with one or fewer indicators of human disturbance and less than 5% total cover of invasive species. Moderate disturbance areas were categorized as those with 2-3 indicators of human disturbance and 5-20% total cover of invasive species.

Figure 2. Camera sampling areas are shown within the study site along I-15 and within the Santa Margarita Ecological Reserve. Sampling areas "A," "B," and "C" are represented by the shaded rectangular blocks. Sampling Area "A1" and "B1", to the west, show where "far road" camera stations for Sampling areas "A" and "B" were placed.

Figure 3. Camera stations, as represented by the colored triangles, are located within Sampling Area A at distances from the road which correspond with the "road's edge (the R in ARW and ARW)," "near road (50 m, points A50W1, A50W2, A50E)," "far road (250 m, points A250W, A250E1, A250E2)," and "unaffected habitat (500 m, A500W1)" identified within the road effect zone. As some camera station locations were changed due to vandalism and flood damage, secondary locations are numbered (e.g. "A250E1" was the original location and "A250E2" was the changed location). Site A500W2 is excluded from this figure because its distance puts it outside the frame of the figure (see Figure 6, below).

Figure 4. Camera stations, as represented by the colored triangles, are located within Sampling Area B at distances from the road which correspond with the "road's edge (the R in BRW1, BRW2, BRE1, and BRE2)," "near road (50 m, points B50W1 and B50W2)," "far road (250 m, points B250W)," and "unaffected habitat (500)" identified within the road effect zone. As some camera station locations were changed due to vandalism, secondary locations are numbered (e.g. "BRW1" was the original location and "BRW2" was the changed location). Site B500W is excluded from this figure because its distance puts it outside the frame of the figure (see Figure 6, below).

Figure 5. Camera stations, as represented by the colored triangles, are located within Sampling Area C at distances from the road which correspond with the "road's edge (the R in CRW, CRE1, and CRE2)," "near road (50 m, points C50W1, C50W2, C50E1, and C50E2)," "far road (250)," and "unaffected habitat (500)" identified within the road effect zone. As some camera station locations were changed due to vandalism, secondary locations are numbered (e.g. "CRE1" was the original location and "CRE2" was the changed location).

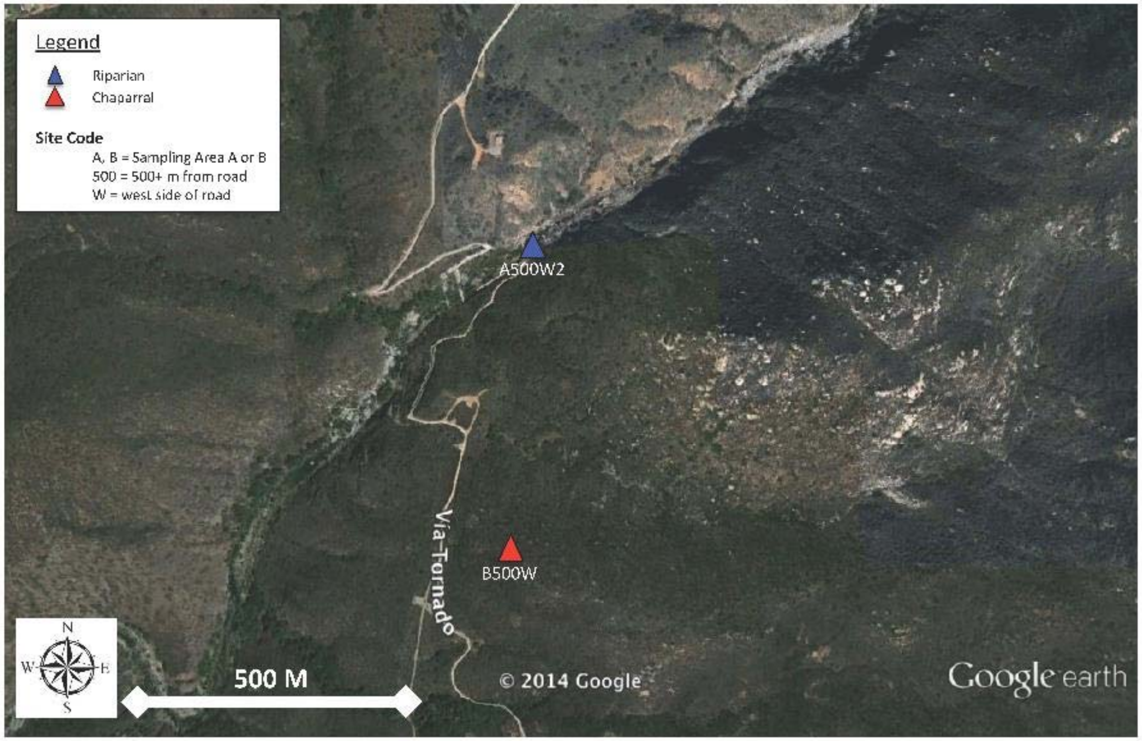

Figure 6. Camera stations, as represented by the colored triangles, are located within Sampling Areas A and B within conserved lands unaffected by the I-15 freeway. These sites are considered "unaffected habitat" as they are at least 500 meters from the I-15 freeway and are located within the Santa Margarita Ecological Reserve.

Camera Placement and Animal Activity

Initial data collection efforts, which included trials of different camera makes and models, indicated that WildGame Micro Red 4 Enhanced^{TM} (Wildgame Innovations, Grand Prairie, Texas) cameras had the best detection rates, motion sensor sensitivity, battery life, resolution, and image clarity for this study.

Stationary cameras were chosen for this study because of their ability to collect data 24 hours a day for weeks at a time. After the initial installation, the cameras require very little maintenance, which allows survey effort to be distributed across a wide spatial and temporal scale while eliminating potential observer bias. One of the drawbacks, however, is that the camera is in fact, stationary. There is no way to detect animals moving behind the camera, outside of the range of the infrared sensors or animals that move very quickly. There is the potential, due to natural variance in ecosystems, that a stationary camera can be placed in an "incorrect" location (i.e. facing away from a major game trail) and thus collect little data leading to artificially low detection rates. To avoid artificially low detection rates, maximize data collection efforts, and for practical concerns, accessibility, terrain, vegetation type, game trails, and sign (e.g. tracks and scat) guided camera placement. All chosen camera sites had at least one indication of animal presence such as a game trail, track, or scat. These sign were aged (one month old or newer) to ensure animal activity was recent. Tracks and scat were aged using guidance from the Mammal Tracks & Sign: A Guide to North American Species guidebook (Elbroch 2003) and with skills acquired during "Trailing Dirt Time" sessions with the Western Tracking Institute in 2012. Scat was aged based on relative moisture present (by sight and touch), relative to weather patterns and moisture (e.g. foggy or rainy days would result in greater scat moisture than hot and sunny days). Tracks were aged based on sharpness of track/relative wear (e.g. relative to substrate and wind/weather patterns), and in some cases oxidation of substrate (e.g. color of dirt). Tracks in dirt and sand often persist longer than those in grasses or other substrate, though not always. Knowledge of weather patterns and substrate is essential to accurate track aging. Whenever possible, track aging was performed early in the morning during cool, non-windy days.

It should be noted that, for at least the coyote, the assumption of equal detectability of individuals within a population is most likely not a reasonable one. At least one study, Larrucea et al. (2007), has demonstrated that individuals captured on camera are more likely to be juvenile, transient, and dispersing individuals (Larrucea et al. 2007 - this study used 17 stationary cameras over a three sampling seasons for a total of over 1043 unique sampling days).

Wildgame Micro Red 4 Enhanced ™ trail cameras were placed in survey locations and left for a fixed period of time to collect video clips of animals that moved near enough to trigger the camera's infrared sensor (which had a manufacturer's reported range of 22.86 meters [75 feet]). Cameras were within 22.86 meters (75 feet) or less of detection areas; boulders, hills, rises, and other landscape elements shortened the distance between camera and detectable areas. Cameras were mounted using either bungee cords or zip ties to t-posts driven into the ground. All cameras were mounted approximately 0.46 meters (1.5 feet) from the ground and facing towards game trails or traveling areas. Unless cameras were vandalized, flooded, or otherwise disturbed, they were left in their original location until the conclusion of the study.

All cameras were set to record when triggered, 24 hours a day, seven days a week with daytime video clips recorded in color and nighttime clips recorded in black and white (infrared). Cameras recorded 30-second video clips along with a date and time stamp, moon phase, and ambient temperature. A 30-second delay between triggers (the camera's minimum delay setting) was set to maximize detections. Camera sensitivity was set to "medium" (during initial field-testing this setting maximized data collection and minimized false triggers). All video clips were recorded on four-gigabyte (GB) SD cards.

The study site was divided into three discrete sampling areas (A-C). For the purposes of analyzing animal activity affected by the road effect zone, distance was used as a surrogate for noise penetration into the surrounding habitat. As noted in Forman and Alexander 1998, the road effect zone is estimated to extend a maximum of 500 feet for noise effects (152.4 meters) with relative effects from the road inversely related to distance from the road. For this study, cameras were then placed in three different road effect zones in each sampling area: road's edge, near road (15 meters, 50 feet), and far road (76 meters, 250 feet). An equal number of cameras were placed on the East and West side of I-15 at the road's edge, and near road. Due to lack of access and permission, the only east location with a far road camera was sample area A. Cameras were also placed in un-affected habitat to monitor the movement of wildlife in the absence of the road effect zone. All road edge cameras were placed at the entrance to a culvert or in an underpass to monitor species' use of these features.

People regularly visited the four survey locations that were closest to the underpass and located in exclusively riparian habitats (site "A"), thus camera theft and vandalism occurred. In addition, unexpected heavy rains flooded and damaged a few of the cameras placed in riparian areas. These events resulted in some data loss and necessary adjustments to camera location and placement. New camera locations were within 25 meters or less of their original location and were within the same road effect zone(s) of their original location. A total of ten cameras were lost to theft and vandalism and five stopped functioning likely due to flooding and rain issues near the riparian area in study site A. Some data were lost to battery life or other malfunctions with an unknown cause. It is difficult to estimate how many data points or sampling days were lost. A camera that is perfectly functional will only collect data when triggered; there were many data sets from functional cameras that did not trigger every day and that would have several days in a row when they were not triggered.

Noise and Distance Analysis

To analyze the relative effect, size, and uniformity of the road effect zone and thus the accuracy of using distance from road as a surrogate for road effect zone and noise effects, traffic noise at each camera station was analyzed. The road's edge, near road, far road, and un-affected habitat were assumed to have an inverse square relationship with decibel (dB) level as a result of distance from traffic noise. That is, it would be assumed that ambient traffic noise volume would decline as a function of the square of the distance to the source (e.g. the road's edge). Therefore, regardless of sampling site (A-C), the same distance from the road on the East or West side should have the same approximate noise level. To test this assumption, noise sampling was performed during the weekday rush hour and the weekend at each camera station. The weekday rush hour is generally considered to be the peak traffic load during which most local residents are driving to work, between 07:00-10:00 and 16:00-19:00, Monday through Friday. The weekend experiences peak traffic loads from 09:00-11:00, but generally has more consistent traffic throughout the day, Saturday and Sunday (CalTrans 2008).

At each camera station, noise was measured using an Extech 407730 Digital Sound Level Meter ™ (Extech Instruments, Nashua, New Hampshire) with a detection range of 40-130 dB. Each noise estimate consisted of a 10-minute sampling period, with a dB reading every minute (to form a site specific average dB) as well as a recorded maximum and minimum dB. All dB levels which fell below the 40 dB detection range of the sound meter were recorded as 39.9 dB; the most conservative estimate of ambient sound. Noise was measured once at each camera station during weekday rush hour in the morning (07:00-10:00) and evening (16:00-19:00) as well as either Saturday or Sunday in the morning (9:00-11:00 am).

Openness Index for SAPML Culverts

To assess the potential for wildlife crossings through the culverts and underpasses in the SAPML, the Openness Index (OI) for each opening was assessed. This was done by measuring the largest part of each end of the culvert opening with a measuring tape to the nearest centimeter. For underpasses that were too high to measure, a laser rangefinder (Trimble LaserAce® 1000 Rangefinder with Digital Compass, Trimble, Sunnyvale, California) was used to determine height. Length of both culverts and underpasses were determined through Geographic Information System (GIS)-based measurements of aerial maps.

Camera Detections

All video clips recorded on SD cards were visually analyzed on a computer using a video playback software program (QuickTime, Apple, Inc., Cupertino, California). A detection of a species was considered positive if any part of the animal appeared on the camera for any period of time during the 30-second video clip. For example, the tip of a tail of a coyote was treated the same as a video of the whole animal. Some camera stations experienced multiple clips that were recorded within minutes of each other (30 second clip with a 30 second delay between clips) of the same species. Often, it was clear that these were the same individuals triggering the camera multiple times (identified by distinguishing physical characteristics such as coat color and patterning). However, at other times, it was unclear if clips of the same species were the same individual or different ones. To remain conservative in estimating wildlife activity, and to avoid overinflating detection rates, species were considered either "detected" or "not detected" on a given sample day at a specific location for the purposes of analyses unless otherwise noted. Therefore, a station with a single coyote detection during a single sample day was given the same weight as a station with multiple coyote detections during a single sample day.

The sole reviewer of data clips was Kelcey Stricker. To maintain consistent detection rates, outside observers were not used for data clip review. If it was not possible to determine the species, clips were marked as "unidentified" and excluded from the analyses.

Detection Rates

For the species of interest, total number of days detected and total number of days of sampling were recorded. A species was recorded as either "detected" or "not detected" for each survey day at each camera station, regardless of the frequency of detection at that station on a single day.

Statistical Analysis

Unless otherwise specified, all statistical analyses were performed using the R open-source statistical software package version 3.0.2 “Frisbee Sailing” (R Core Team 2013).

To determine the potential effect noise pollution from the I-15 freeway may be having on the mammalian community composition within the SAPML, distance from the road was used to try to predict type of species detected. Because track data were count-based (discrete), and in each case data did not meet the assumptions of a Poisson count model, but did meet the assumptions of a negative binomial regression (i.e. all had goodness of fit p-values greater than 0.05 with this model). Predictors included camera station distance from the road as categorical variables (road, near road, far road, unaffected). Response variables included number of days each species was detected for coyote, gray fox, bobcat, rabbit, opossum, raccoon, and skunk; mountain lion and ringtail were excluded from this analysis due to lack of data. The number of days sampled was used as an offset, which is the exposure time for the data point, and the slope coefficient for the offset is assumed to be 1; the offset has the effect of making the predictors model the response on a proportional scale, and since its value is assumed, including an offset does not consume degrees of freedom. In effect, this modeled the proportion of days of sampling resulting in detections (detection rate), using a count model. An additional negative binomial regression was performed with habitat type (disturbed, large culvert, oak woodland, riparian, small culvert, and underpass) as predictors and detection indices for species as response variables.

To summarize results across the community of mesopredators included in the study, a Canonical Correspondence Analysis (CCA) was performed to determine if distance from road, and the assumed road effect zone, effected the community composition. CCA seeks to find patterns of change in species composition, as a function of specified predictors. Whereas the negative binomial regressions would detect changes in detection rates attributable to distance from the road for a species, differences in rates of change in detections among the species could result in changes in the composition of the community. The CCA thus summarizes the responses across all the species, and expresses the results in terms of changes in relative abundances at different distances. There can be more than one pattern of change in species composition, and CCA can identify as many "axes" of change in composition as there are predictors. The strongest pattern (called CCA Axis 1, or CCA1) is found first, and subsequent axes characterize successively weaker patterns of change in composition. Randomization tests can be used to identify a significant CCA overall, and to test the significance of each CCA axis.

Mountain lion data were dropped from these and all subsequent analyses due to lack of detections overall to avoid skewing of the data; only one lion clip was captured during the course of the study, and rare species are known to have large effects on CCA results. Because a CCA is used to look at patterns of change in composition, having a single detection of a single species in only one area can have the appearance of a significant or noteworthy result when, in fact, it is simply a reflection of lack of detections in other areas. While the CCA may indicate that lions are detected more frequently in a given community of animals near riparian areas, it is simply the lack of lion detections in all other areas that are giving this result. A CCA was also performed to examine the possible relationship between habitat types at each site and species composition at each site.

To analyze how species may be avoiding each other temporally while still occupying the same space spatially, timestamps on the data clips were recorded and analyzed. Circular statistical analysis, a type of analysis designed specifically for predictors that are cyclical in nature (i.e. moon phase, 24-hour clock) was used to examine these data. For this analysis, all time stamps on video clips analyzed were recorded in a 24-hour clock format and then converted to radians and plotted on a circle. The "circular" package in R was used to perform the analysis (Agostinelli and Lund 2013). For this analysis, all video clips for the focal species recorded were used; a detection index was not needed because the patterns of usage being analyzed were based on time of day, not total number of detections. It is possible that different detections are of a single animal (thus this analysis is actually looking at patterns of use by individuals within a species rather than the species as a whole), however, using an average time of day for detection would not be worthwhile as many species are diurnal and averaging would mask these patterns of use.

Results

Noise and Distance

There were three sample areas within each distance category and average traffic noise levels were taken at each one. These average site values ranged from 67-52 dB at the road's edge, 69-51 dB near road (15 meters, 50 feet), 70-52 dB far road (76 meters, 250 feet), and 44-55 dB in undisturbed habitat (≥ 152.4 meters, 500 feet). It should be noted that the noise meter's detections were indiscriminate; in undisturbed habitat, airplanes flying overhead and a rapidly flowing river produced approximately the same dB level. However, this only effected maximum dB level; overall, the average dB level was lower in undisturbed habitat, reflecting the expected results of greater dB levels as a result of closer proximity to the road's edge. The noisiest site was B250W at 71.91 dB (Table 1).

Table 1. Mean, minimum, and maximum decibel (dB) levels of ambient noise at all camera sites (as identified by Site ID), as measured in the field. Noise levels were measured using equipment that detected noise levels between 40-180 dB. For detections that fell below the detection range for the equipment (e.g. below 40 dB), the detection was identified as “lo.” In this table, “Mean (dB)” is based on a 10 minute running average. Site ID abbreviations are as follows: BRW=Site B, road’s edge, West side of I-15, BRE=Site B, road’s edge, East side of I-15, CRW=Site C, road’s edge, West side of I-15, CRE=Site C, road’s edge, East side of I-15.

Site ID	Distance	Sampling Area	Mean (dB)	Min (dB)	Max (dB)
ARW	road's edge		67.87	53.6	79.1
A50W	near road		61.65	51.3	76.1
A250W	far road		51.73	46.7	61.6
A500W	undisturbed habitat	A	54.38	lo	63.3
B250W	far road		71.91	56.6	79.8
B50W	near road		68.94	56.3	78.6
BRW	road's edge		61.79	43.3	78.8
BRE	road's edge		52.4	lo	67.5
B500W	undisturbed habitat	B	55.6	lo	57.6
CRW	road's edge		69.6	52.8	80.5
C50W	near road		66.57	55.4	78.2
C50E	near road		55.55	50.3	64.9
CRE	road's edge		56.46	49.7	77
C500W	undisturbed habitat	C	44.25	lo[2]	68.9

Openness Index

The measured and calculated OI for almost all culverts found running underneath the I-15, including those sampling in sites B and C, were less than 0.1. This OI is considered a “Type 1” (Acensao and Mira 2008) and predicts only small mammals would use these structures.

Table 2. Culverts within the study site as characterized by their Openness Index (OI), their surrounding vegetation communities, and with qualitative notes ("Other notes"). "Diameter" indicates the size of the diameter of the opening. Length of the culverts was determined through GIS analysis. The OI was calculated using the diameter and the length; the resulting numerical OI was then used to classify the type of culvert based on the classification system used in Acensao and Mira (2008). Site ID abbreviations are as follows: BRW=Site B, road's edge, West side of I-15, BRE=Site B, road's edge, East side of I-15, CRW=Site C, road's edge, West side of I-15, CRE=Site C, road's edge, East side of I-15.

Site ID[1]	**B R W**	**B R E**	**OI[2]**	**C R W**	**C R E**	**OI**
Culvert	West Entrance	East Entrance	Type 1	West Entrance	East Entrance	Type 1
Type	Corrugated metal/Circular	Corrugated metal/Circular		Corrugated metal/Circular	Corrugated metal/Circular	
Diameter	2 meters	2 meters		1.15 meters	1.5 meters	
Other notes	Sediment buildup on western extent	Golf course; some moderate disturbance by maintenance crews		Metal and cement substrate (constrains size of culvert to 1.1 meters top-bottom)	Standing water year-round; large woodrat midden	
Vegetation	Oak Sycamore Riparain Woodland	Willow and open/bare ground (sandy wash)		Oak Woodland (medium dense with moderate canopy cover and developed understory of poison oak	Willow (moderately dense canopy cover) and riparian dominated by cattails and poison oak	

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Both weekend and rush hour noise data were collected, but there was no significant difference in dB levels between the two sampling time periods. For example, at site a, weekend rush hour (mean=57.93, sd=5.85) and weekday rush hour (mean=57.32, sd=5.95) were not found to be statistically different from one another based on a two-tailed t-test (p=0.89). Rush hour traffic noise data were used to represent the average, minimum, and maximum dB level at each camera station (Table 1).

The relationship between distance and dB level was analyzed by fitting a linear model. A linear regression was used to analyze the potential relationship between distance, as a categorical variable ("road's edge", "near road", "far road", and "undisturbed"), and average dB; this yielded significant results (p=0.048, df=16). Due to site-to-site variation in actual distance from the road, a linear regression was used to analyze the potential relationship between actual distance (as determined by GIS analysis) and dB level. These results were also significant (p=0.037, df=16). These resulting correlations were strong enough to suggest that distance was a reasonable surrogate for dB level for the purposes of subsequent analyses and interpretation.

Detection Rates

Across all camera stations, the total number of sampling days was 1043 (number of days each camera was actively functioning and collecting images). Of the approximately 765 video clips of animals collected throughout the course of this study, 232 had positive detections of one or more of the focal species. The most commonly observed species in the study was the coyote with 85 total detection days across all camera stations. Raccoon and gray fox were the second and third most commonly observed species with 52 and 33 detection days, respectively. Mountain lion was the least commonly observed species with only one detection day. Ringtail was also uncommonly observed with 6 detection days.

A detection index was calculated to account for different numbers of detection days at different camera stations. The number of sample days was divided by the number of detections at the camera station to show consistency of wildlife activity at a given camera station area. For this calculated value, no attempt was made to distinguish between individual animals; all wildlife detections were treated with equal weight. Detection indices for each site and each species are listed in the tables below and were used for statistical analyses unless otherwise noted (Tables 3 and 4).

Table 3. Detection indices by site for all focal species detected. The "Sample Days" are the number of days the camera was actively collecting data. The "Detections" are the number of focal species captured during those sample periods. The "Detection Index" is the number of detections divided by the number of sample days, which allows for comparison of detection rates across sites, given unequal sampling days. Site ID abbreviations are as follows: BRW=Site B, road's edge, West side of I-15, BRE=Site B, road's edge, East side of I-15, CRW=Site C, road's edge, West side of I-15, CRE=Site C, road's edge, East side of I-15.

Site ID	Sample Days	Detections	Detection Index
A250E	30	15	0.50
A250W	45	11	0.24
A500W	14	0	0.00
A50E	44	14	0.32
A50W	40	33	0.83
ARE	51	30	0.59
ARW	52	1	0.02
B250W	96	9	0.09
B500W	24	7	0.29
B50W	85	13	0.15
BRE	38	12	0.32
BRW	54	10	0.19
C500W	6	4	0.67
C50E	106	18	0.17
C50W	165	34	0.21
CRE	52	16	0.31
CRW	141	5	0.04

Table 4. Detection indices by site for each focal species detected. The "Detection Index" is the number of detections divided by the number of sample days, which allows for comparison of detection rates across sites, given unequal sampling days; this is represented as a numerical value in this table. Site ID abbreviations are as follows: BRW=Site B, road's edge, West side of I-15, BRE=Site B, road's edge, East side of I-15, CRW=Site C, road's edge, West side of I-15, CRE=Site C, road's edge, East side of I-15

Site ID	Coyote	Gray Fox	Opossum	Bobcat	Mountain Lion	Ringtail	Raccoon	Rabbit	Skunk
A250E	0.20	0.00	0.03	0.03	0.00	0.00	0.23	0.00	0.00
A250W	0.13	0.00	0.02	0.00	0.00	0.00	0.02	0.07	0.00
A500W	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A50E	0.23	0.00	0.02	0.05	0.00	0.00	0.02	0.00	0.00
A50W	0.38	0.00	0.03	0.13	0.00	0.00	0.13	0.15	0.03
ARE	0.37	0.00	0.08	0.04	0.00	0.00	0.06	0.02	0.02
ARW	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B250W	0.05	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00
B500W	0.00	0.04	0.00	0.00	0.04	0.00	0.00	0.00	0.21
B50W	0.05	0.01	0.05	0.00	0.00	0.00	0.02	0.02	0.00
BRE	0.03	0.00	0.00	0.05	0.00	0.00	0.18	0.00	0.05
BRW	0.00	0.09	0.00	0.00	0.00	0.00	0.09	0.00	0.00
C500W	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.17
C50E	0.10	0.00	0.00	0.00	0.00	0.00	0.01	0.06	0.00
C50W	0.02	0.14	0.00	0.00	0.00	0.04	0.01	0.00	0.00
CRE	0.04	0.00	0.00	0.00	0.00	0.00	0.27	0.00	0.00
CRW	0.01	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00

Statistical Analysis

A negative binomial regression with categorical distance as a predictor and species detection as a response yielded no significant results. Negative binomial regression with habitat type as a predictor and species detection as a response yielded significant results for bobcat (p=0.0009, df=11), coyote (p=0.016, df=11), and fox (p=0.003, df=11).

No significant association was found between habitat type and species composition using CCA, based on a randomization test of the CCA. The "scores" from a CCA are numeric representations of species composition, which can be used as numerical data in other analyses. To confirm that the first CCA did not differ by habitat, an ANOVA was performed on CCA1 scores among habitat types, which was non-significant (model: p-value=0.168, df=5, F=1.2194). Interestingly, a tri-plot that overlays species, habitat, and sampling point numbers shows that raccoons are more common near culverts, dogs and humans are more common in disturbed areas, and foxes, rabbits, and ringtail are more common near oak woodlands (Figure 7); however, since the tests of significance fail the standard benchmark p-value of 0.05, these patterns should be treated at suggestive, but not conclusive evidence of variation in community composition by habitat type in this area.

In addition, no significant correlation was found for distance from road and species detections, max dB and species detections, min dB and species detections, and average dB and species detections.

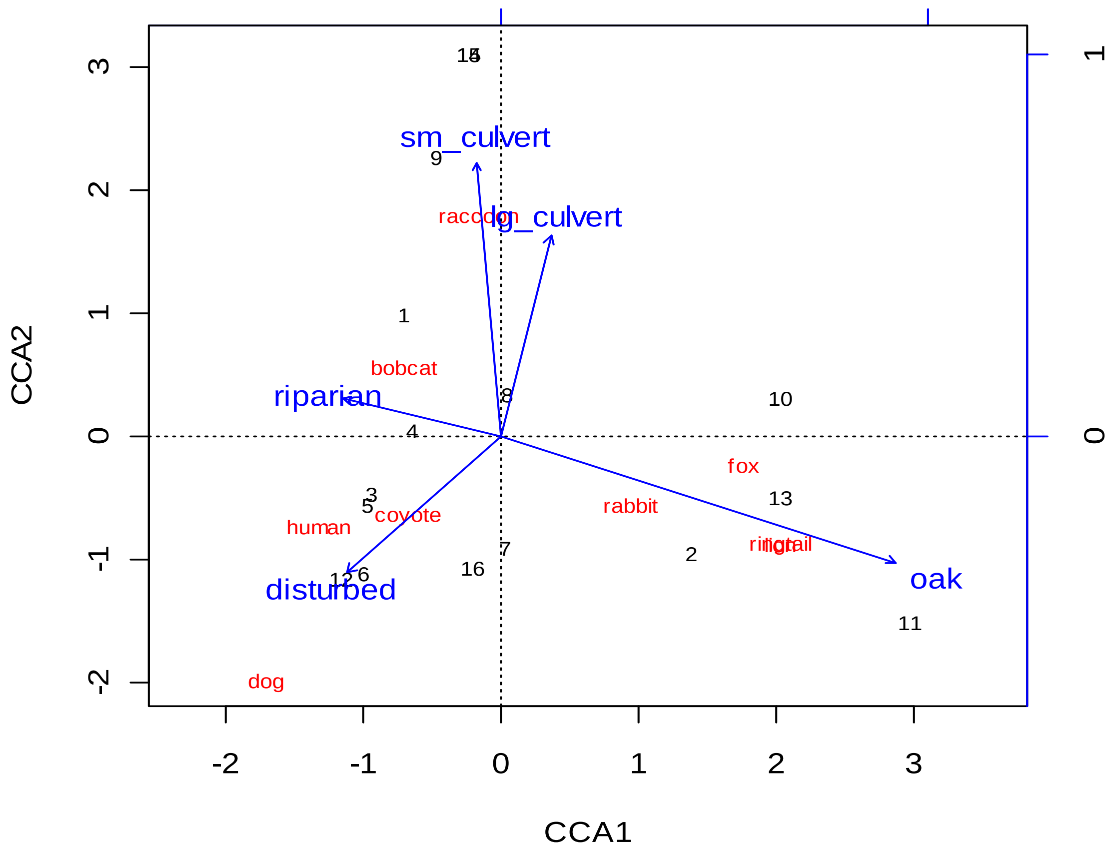

Figure 7. A triplot of the Cannonical Correspondence Analysis (CCA) of species and habitat type for all camera stations in the study area. This triplot visually demonstrates the observed correlation between habitat type and species detection rates. The effect of habitat type on species composition is shown by the arrows. Species that are found primarily in a particular type of habitat lie in the direction of the tip of that arrow. The closer to the end of the arrow the species lies, the greater the correlation; species closer to the center have a lower correlation with that habitat type.

In the triplot coyotes and humans appear to be associated with disturbed habitat and both ringtails and foxes were associated with oak woodland. An analysis of habitat use patterns, based on time, was performed using circular statistics. The initial analysis produced an average vector length for each species; equivalent to the average time of day (on a 24-hour clock) that species was detected. A circular ANOVA was performed on the species vectors and produced a significant result ($p<0.001$, df=12, $chi^2=90.25$); thus different species were not necessarily active at the same time. Six post-hoc analyses were performed on pairs of species which were thought to have significant relationships by sub-setting the data and running the analyses again (on pairs of species). An attempt to minimize the loss of power from multiple analyses was made by limiting the post-hoc tests to just six pair-wise comparisons with the potential to have a significant relationship (based on literature, initial study, and knowledge of study site). To account for loss of power from the multiple analyses, a Bonferoni correction was applied (p=0.05/6=0.008). Three of these comparisons were significant (Table 5).

Table 5. Post-hoc analysis of a circular Analysis of Variance (ANOVA) with pairs of species that may have a significant relationship. Chi-squared values and p-values are displayed. A Bonferoni correction was applied (p=0.05/6=0.008), therefore those p-values which are significant have been identified with an asterisk.

Pair of Species	**Chi^2**	**P-Value**
Bobcat.Gray Fox	6.41	0.01135
Coyote.Bobcat	11.91	0.0005573*
Coyote.Domestic Dog	12.61	0.0003844*
Gray Fox.Raccon	0.2774	0.5984
Bobcat. Domestic Dog	0.9809	0.322
Human.Coyote	9.655	0.001888*

A problematic characteristic of circular statistics is that when there is a result of "no difference," it can be because neither of the species being analyzed is active at a specific time of day or because they are both active at the same time of day. A Rayleigh test of uniformity was performed on each species to help with interpretation of the non-significant results. A uniform distribution (e.g. times of detection are distributed evenly throughout the 24-hour day) yields a single point at the center. A non-uniform distribution indicates a vector with a non-zero length, and the direction of the vector indicates the time of day of concentrated activity. Resultant vector magnitudes are displayed as a value between 0-1 with 0 indicating a uniform distribution and 1 indicating all values at a single time in the 24-hour clock. The results of the Rayleigh test are displayed in Table 6. All species exhibited significant directionality except for bobcats; thus, non-significant comparisons of active times indicate that species are active at the same time, except for comparisons with bobcats.

Table 6. Rayleigh vector magnitudes of focal species detection times in degrees. Vector magnitudes are a measure of directionality between 0 (no directionality) and 1 (all observations at the same time of day).

Species	**Vector Magnitude**	**P-Value**
Coyote	0.4964	<0.001
Ringtail	0.9171	<0.001
Bobcat	0.3558	0.1503
Domestic Dog	0.9301	<0.001
Gray Fox	0.579	<0.001
Human	0.878	0.0042
Opossum	0.8407	<0.001
Rabbit	0.5629	<0.001
Raccoon	0.5115	<0.001
Skunk	0.6724	0.0026

Culvert Usage

Although the cameras at the road's edge were set at the entrance to two culverts (Sites B and C), only a few instances of culvert usage by the target species were observed. It is important to note that these culverts were characterized as having a Type 1 OI (Table 2), and are expected to only support the crossing of rats, weasels, and mustelids (Ascensao and Mira 2006). During the course of the survey, video clips captured bobcat, gray fox, and raccoon entering and exiting these culverts. Clips of bobcat and gray fox were relatively rare, with only one instance of bobcat entering, one instance of gray fox exiting. Clips of raccoon were relatively more common with approximately five clips of raccoons entering and exiting. These clips of entering and exiting were distinguished from those which show a bobcat approach, hesitate, and turn around, as well as those that show raccoons moving in and out of culverts fishing and drinking water accumulated in those areas. While there are not enough data clips to support anything outside an anecdotal observation of entering and exiting, it is important to note that these observations contradict the predictions of the often-used OI.

The ringtail observations occurred on the East and West side of Site C. That the relatively difficult to detect ringtail (Feldhamer et al. 2003) was observed multiple times, coupled with the observations at both the east and west entrances of the culvert in Site C and the ringtail's reputation for cave and mine dwelling (hence the nickname "miner's cat") strongly suggests that this is the same individual. If this is the case, then the ringtail is using the culvert as part of its habitat and to access the standing water on the east side entrance.

Discussion

Multiple studies have looked at culverts, connectivity, and the effects of roads on different groups of mammals. However, previous studies have focused on roadways that had fewer lanes and lower annual daily traffic averages than the SAPML (which previous studies?...cite examples of them here unless you plan to discuss them in detail later…which I do not see below). This study has focused on the relative utility of a wildlife corridor, which is bisected by a heavily traveled road in rapidly urbanizing southern California. The following sections highlight several key areas where this study has increased understanding of wildlife movement and the affects of the I-15 freeway on the SAPML. How species were observed to respond to distance from road, culvert presence, noise, and habitat are all key factors that will inform future management decisions and applications in this unique linkage. The long-term conservation and management of the SAPML is an important factor in maintaining populations of mammals in the study area; any insight into the functionality of this linkage and how to improve it is an essential factor in preserving landscape level connectivity.

Noise and Distance

While the distance from the road was inversely related to dB level generated by the road for most camera stations, one site did not follow this pattern. Site B250W was consistently louder than other camera stations in survey area B that were closer to the road. This was likely due to its relatively higher topographic position compared to the sites next to the road, as well as less dense vegetation, allowing the traffic noise to travel further before reaching B250W. This may have affected the detection rates at this camera station.

The noise levels measured ranged from 40-180 dB and were based on sound detectable to the human auditory system (e. g. ear). This standard was used because this is the range typically used to make conservation decisions. While many species perceive noise and vibrations in many different ways, the California Environmental Quality Act (CEQA), CalTrans, and local policies and ordinances rely on the A-weighted decibel (dBA) and the one-hour equivalent sound level (L_{eq}[h]) for informing conservation decisions. As a result, these were the standards used for this study. For example, CalTrans considers a "substantial noise increase" to occur only when "the project's predicted worst-hour design-year noise level exceeds the existing worst-hour noise level by 12 dBA or more." This level was based on the concept that "a 10 dB increase generally is perceived as a doubling of loudness" (California Department of Transportation 2011, page 6).

While this may not be the most accurate way to assess an animal's perception of sound, the human perception of loudness and noise is the standard for conservation based decision making.

The average noise levels at each site, as well as the recorded minimums and maximums at each site, showed little variability between weekday and weekend survey periods, suggesting the noise output from I-15 is relatively consistent over time. While weekday rush hour had more vehicles overall, the slower speeds induced by heavy traffic were likely responsible for reducing the noise levels. The weekend traffic consisted of fewer vehicles, which were traveling at faster speeds, as well as motorcycles and sports cars that produced a greater volume of sound despite the low numbers of automobiles.

Overall, noise levels detected appeared to have a minimal affect on mammalian community composition. The literature would suggest that the road effect zone would have a significant negative affect on native carnivores and mesopredators by reducing the number of individuals that would approach the road's edge (Fletcher 1980, Fletcher 1990, Larkin et al. 1996). Other studies on the road effect zone suggests that noise from traffic repels carnivores and mesopredators, limiting the number of individuals who approach the road's edge and culverts and, thus, limiting the number of potential and successful crossings over and under a road (refs?). This study was unable to replicate this effect for this particular study area. For coyote, bobcat, ringtail, and dog, the strongest predictor for detection of a particular species was the habitat type where the camera station was located. This suggests that, when habitat is high quality and/or a road passes through conserved and undeveloped lands, carnivores and mesopredators are approaching the road's edge despite the noise pollution and are, perhaps, desensitized to the effects of vehicle noise.

It should be noted that, due to time, budget, and access constraints, all cameras placed at the road's edge were located at the entrance to a culvert or underpass. Thus, it is not possible to distinguish in the data and analysis between an effect of the road's edge and an effect of a culvert or underpass entrance. The triplot (Figure 7) suggests an affinity for culverts by certain species, but this could also be an effect of proximity to road; the CCA on which Figure 7 is based, however, was non-significant, and this result should be treated as suggestive of associations, but would require a larger study to confirm.

Animal Detections and Avoidance

There is a significant body of literature demonstrating that, in the presence of human activity and developments, carnivores and mesopredators will change their activity patterns to different times of day (Fletcher 1980, Fletcher 1990, Larkin et al. 1996, Atwood et al. 2007, Darrow & Shivik 2009). Specifically, coyotes have been shown to switch from primarily diurnal activity to nocturnal activity to avoid humans (Kitchen et al. 2000). In Kitchen et al. (2000), the activity patterns of coyotes tracked via telemetry in areas of high persecution by humans (e.g. trapping and shooting by ranchers) were highly nocturnal versus the activity patterns in areas of low persecution (e.g. occasional military training exercises) even when accounting for potential changes in prey availability.

The analysis of time of day use patterns in this study suggests there is a significant avoidance of coyotes and humans even though both species occupy the same habitat. In addition, literature demonstrates that coyotes will shift their behavior in response to human presence (Gese et al. 1989, Kitchen et al. 2000, Atwood et al. 2007). As Atwood et al. (2007) demonstrated, coyotes avoid urban areas and farmland and appeared to have similar responses to different levels and types of human activity. While suburban residents often associate coyotes with urban and developed areas, Atwood et al. (2007) demonstrated that coyotes preferentially use patches of undeveloped habitat within urban areas, avoiding human presence and activity. Within this study area, it is reasonable to expect that coyotes have shifted their habitat use patterns in response to human activity in the area.

Coyote and bobcat are also known to be active at different times of day, however their habitat associations do not significantly overlap (Figure 7). While coyote are often seen in riparian habitat where bobcats are also frequently detected, bobcats are rarely seen in disturbed habitat, where coyotes are frequently detected. This lack of bobcat presence in areas were coyote are found, while attributed to inter-specific avoidance in literature (Crooks and Soulé 1999, Fedriani 2000), can be attributed to a number of factors such as habitat association, or resource partitioning and may not necessarily be attributed to inter-specific avoidance (Neale and Sacks 2001). This is supported by the CCA analysis is this study, which suggests a relationship between habitat and species detected there (Figure 7).

Coyote and domestic dog, however, are known to have inter-specific conflicts (Palomares and Caro 1999, Gompper 2014). In this study area, both species are associated with disturbed habitat and yet are both are using the habitat at different times. This could suggest inter-specific avoidance, however, it is also possible that domestic dogs are only associated with human activity.

In this instance, the avoidance of humans and avoidance of domestic dogs cannot be separated and are, in fact, the same response. Domestic dogs recorded were, universally, “off-leash.” Some of the dogs recorded had collars and others did not. Only one was associated with a human presence, as recorded by the camera station. If humans were associated with the other domestic dog camera captures, the humans were outside the capture range of the cameras and not recorded. It is difficult to ascertain whether the uncollared or collared domestic dogs were feral or otherwise cared for by owners, so it is impossible to tell how closely domestic dog presence was linked to human presence.

The human presence measured at the camera sites was incidental and not a targeted species as part of this study. Some of the people detected were hiking or riding horses through the study area while some appeared to be camping and living in the area. Still others detected were, likely teenagers, painting graffiti and staying in the area for short periods of time.

SAPML Functionality

There are three important conclusions to be drawn from this study: 1) the road effect zone as defined by the noise gradient (e.g. dB level) measured (40-180 dB) is not a significant predictor of carnivore and mesopredator community composition for the SAPML; 2) human and domestic dog activity in the SAPML may be affecting coyote movement in the SAPML; 3) the OI for the culverts running under the SAPML is not a significant predictor for species usage in the SAPML.

If functionality of the SAPML is defined as carnivores and mesopredators actively approaching and crossing either over or under the I-15, then the SAPML is functional. If functionality includes preserving the genetic integrity of these mammalian populations through sustainable levels of gene flow between the East and West side of the I-15 through the SAPML, then more research needs to be performed before this can be determined.

Conversations with the Pechanga Band of Luiseño Indians Environmental Department suggest that species composition in eastern contiguous habitat within the SAPML is comparable to that within the Santa Margarita Ecological Reserve (Newman, pers. communication 2013). Although sampling was not possible on the Eastern side of the SAPML due to lack of access, it is reasonable to postulate that mammalian species composition and mammalian community response to I-15 is approximately equal on the eastern side of the SAPML.

I-15 Effects on the SAPML

The actual effect of I-15 on SAPML is likely varied and complicated. The I-15 as a whole has been in existence since 1957, but the "Temecula Valley Freeway" segment of I-15, which replaced the "Old 395," was completed in 1985. This affected area is unique in that the habitat surrounding I-15 is primarily intact native habitat known to support sensitive animal species (MSHCP 2003). Lands within the study area that are considered conserved or preserved open space include the Santa Margarita Ecological Reserve (SMER) to the West of I-15, and Pechanga Indian Reservation and Bureau of Land Management (BLM) parcels to the East of I-15. In addition, I-15 is a wider road with higher daily traffic volume than those studied in previous road-effect zone and wildlife movement studies. The relative value of the SAPML for wildlife is dependent on the size and intensity of the road-effect zone and its affect on the movement patterns of native wildlife. Evidence suggests those species most sensitive to fragmentation, noise, and roads, such as carnivores and mesopredators, are those who will be most significantly affected by the presence of the I-15 within the SAPML (Beier 1995, Jaeger et al. 2004, Fahrig and Rytwinski 2009).

The results of this study, especially with regard to culvert usage and response by the mammalian community to noise, are incongruous with other studies. There are multiple possible explanations for this. The majority of the culvert and connectivity work performed in other study areas by other researchers was based on roads and freeways that had significantly fewer lanes—sometimes only 1-2 lanes in either direction. It is possible that the results seen on a small road, in terms of which mammals are willing to utilize culverts, cannot be extrapolated out to larger roads, such as the I-15. The same could be true of noise effects. Because the I-15 has been in place since 1985, there are likely no individual animals that have not been exposed to the levels of traffic noise currently being produced. Highways with fewer lanes and less traffic, or more fluctuation in traffic—such as the Trans Canada Highway into Banff National Park which experiences a tourist season—may have a greater noise affect on the mammalian community, because it has not been habituated to consistently higher noise levels. While the results of this study are primarily applicable to the SAPML area, the idea that results from one system cannot always be extrapolated or applied for management decisions in a different system is an important one.

What this says about large systems, such as the SAPML, is that, just because an affect is larger (e.g. the I-15 is an exceptionally wide and well-traveled road), does not mean that the negative effects to the mammalian community are proportionally larger. Bigger does not necessarily mean worse.

Conservation Applications and Recommendations

The SAPML has been identified as one of two priority linkages for the state of California, and as a "special linkage area" by the MSHCP (MSHCP 2003, Bunn et al. 2007). The results of this research can be used to guide certain conservation practices that could enhance the protection and usage of the SAPML and other similar linkages. What is important to keep in mind is that the SAPML is a wildlife linkage and, thus, is focused on preserving connectivity for multiple species. Therefore, enhancement and protection measures for wildlife movement are also varied.

While noise has been show to affect behavior and movement in carnivores and mesopredators, this future conservation and management of the SAPML should take into account the fact that noise in the road effect zone is likely not the main barrier to movement. In fact, many different species are using the culverts that run under the I-15 to circumvent road hazards. What is not clear is how effective the culverts are, in their current condition, for facilitating wildlife movement. While movement of multiple species of carnivores and mesopredators through the culverts has been demonstrated, further study on the genetics of these populations needs to be performed. Only with a genetic study can we estimate the degree of isolation, if any, these species are experiencing as a result of the I-15 freeway's path of travel through the last inland-to-coastal linkage in southern California.

Based on the capture rates of data by cameras, it would make the most sense to perform hair-snare based genetic sampling at both the East and West entrances to the culverts. This will help determine if multiple individuals of the same species are using these crossings, or if only one or two individuals are using these crossings. It will also help determine which crossings are preferred by which species and/or individuals, and if family groups are more likely to use certain culverts or game trails. This will further aid future conservation efforts by focusing land managers on the best locations for culvert retrofitting activities or the location of a potential wildlife overpass.

Retrofitting culverts can include increasing the size, changing the shape, or otherwise making these drainages more desirable to carnivores and mesopredators for crossing. The strong affinity for habitat type demonstrated in this study should inform management efforts in the future by ensuring appropriate habitat and cover in areas where carnivore and mesopredator movement is desirable. Habitat type is strongly associated with species presence, so reduced disturbed habitat, especially near culvert entrances, is likely to facilitate movement. As noise near the road's edge does not appear to be a strong deterrent for carnivores and mesopredators in this study area, increasing native habitat may entice additional individuals to the culvert entrances.

Species' affinity for specific habitat types can also be used to guide habitat conservation efforts, such as the purchase of parcels of land within the SAPML footprint. There are many parcels of currently undeveloped land which are in private ownership or otherwise unprotected. As part of the linkage protection efforts, there is currently a desire to conserve lands within the modeled SAPML footprint (Z. Principe pers. comm.). Habitat type within the SAPML footprint on unprotected parcels can be used to prioritize those areas in need of conservation for certain species of interest. For example, if conservation of the fully protected ringtail is a priority, parcels with oak woodland can be targeted for conservation. To ensure the active usage of the SAPML in the future, habitats of different types should be conserved within the footprint of the linkage to support usage by a variety of carnivore and mesopredator species.

Usage of the SAPML and movement of carnivores and mesopredators can also be preserved and enhanced by eliminating the human presence within the linkage. Various literature and the results of this study support the idea that, in the presence of any human activity, carnivores and mesopredators will change their activity patterns. This can affect their usage of the linkage for both dispersal and foraging and hunting opportunities, ultimately effecting the success and survival of various populations.

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