DISTRIBUTION, RELATIVE ABUNDANCE, AND ROADWAY UNDERPASS RESPONSES OF CARNIVORES THROUGHOUT THE PUENTE-CHINO HILLS

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THESIS: DISTRIBUTION, RELATIVE ABUNDANCE, AND ROADWAY UNDERPASS RESPONSES BY CARNIVORES THROUGHOUT THE PUENTE-CHINO HILLS

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ABSTRACT

Track surveys were conducted across the Puente-Chino Hills wildlife corridor to determine associations between the distribution and relative abundance of mammals and several landscape variables. Landscape variables were factored into a single variable representing fragmentation. The fragmentation variable was positively associated with the distribution (probability of occurrence at a track transect) and relative abundance (frequency of occurrence at a track transect) of mule deer, striped skunk, domestic dog, and domestic cat and negatively associated with the distribution and relative abundance of bobcat and long-tailed weasel.

Underpasses along seven roadways were monitored to determine associations between the probability and frequency of underpass usage and several landscape and underpass dimension variables. Fragmentation was positively associated with the probability of underpass usage for domestic cats and negatively associated with the probability of underpass usage for coyote, bobcat, and long-tailed weasel. Fragmentation was negatively associated with the frequency of underpass usage for bobcats.

Underpass dimensions were only important in determining the probability of underpass usage for gray fox and mule deer. Coyote, gray fox, mule deer, and domestic cat frequency of underpass usage increased at underpasses that were more open. The amount of natural cover surrounding the underpass entrance was important for bobcat. Fencing and roadway dividers were most effective on coyote use of underpasses. Overall, the probability of underpass usage was primarily dependent on the surrounding landscape

variables. The frequency of underpass usage was primarily dependent on the specific underpass dimensions.

Given the responses to fragmentation exhibited by bobcats, they represent an excellent target species for conservation in the Puente-Chino Hills. Several measures can be made to enhance connectivity of carnivores throughout this corridor. Habitat acquisition and restoration should be concentrated along the narrowest portions of the corridor and at choke points along roadways. Existing underpasses should be surrounded by natural cover and contain proper fencing to direct wildlife under the roadway. Future underpasses should be large enough to facilitate mule deer movement and should be situated as far away from residential areas as possible.

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INTRODUCTION

Habitat fragmentation has been targeted as one of the most serious threats to biodiversity worldwide (Wilcox and Murphy 1985; Saunders et al 1991). Fragmentation typically leads to the isolation of populations, thus creating local subpopulations scattered across a landscape (Dobson et al. 1999). Isolation of these subpopulations may lead to local extinctions due to the lack of genetic exchange with other individuals from different populations (Hanski and Simberloff 1997; Hanski 1999). Additionally, fragmentation results in landscapes that lack heterogeneity as well as pose specific threats to population viability (Noss and Cooperider 1994; Noss and Csuti 1997). In southern California, fragmentation of the landscape has reduced much of the remaining habitat and the effects of fragmentation have had negative consequences on populations of birds (Soulé et al.1998; Bolger et al. 1997; Scott and Cooper 1999) and mammals (Beier 1993, 1995; Crooks and Soulé 1999).

Species that display a high vulnerability to fragmentation include those that are wide-ranging, exhibit low population densities, or are large-patch or interior-dwelling species (Noss and Csuti 1997). Large mammals, particularly carnivores, exhibit these characteristics, but their decline in fragmented systems has received little attention (Beier 1995; Noss et al. 1996; Reed et al. 1996). The disappearance of top predators from fragmented systems may have community-wide implications (Sovada et al. 1995; Ralls and White 1995; Terborgh et al. 1999) and may lead to the ecological release of mesopredators (Sargeant et al. 1983; Soulé et al. 1988; Sovada et al. 1995; Crooks and Soulé 1999).

To counteract the negative effects of fragmentation on populations, the concept of wildlife corridors has been proposed (Harris and Gallagher 1989; Noss and Cooperrider 1994; Dobson et al. 1999). The exact definition of a corridor varies and can include habitat linkages, greenbelts, biogeographic landbridges, refuge systems, and roadway underpasses (Simberloff et al. 1992). Generally, the accepted definition describes a corridor as a linear habitat, embedded in a dissimilar matrix, that connects two or more larger blocks of habitat (Beier and Noss 1998). Additionally, it is recognized that the corridor is proposed for conservation on the grounds that it will enhance or maintain the viability of specific wildlife populations (Rosenberg et al. 1997). Noss (1987) suggests several potential advantages to corridors, including increased species richness and diversity, decreased probability of extinction, maintenance of genetic variation, a greater mix of habitat and successional stages, and alternative refugia from large disturbances. Alternatively, Simberloff and Cox (1987) list potential disadvantages to corridors, including the facilitation of epidemic diseases, outbreeding depression, facilitation of the spread of fire, and increased exposure to humans.

While there has been great debate over the values and shortcomings of corridors, there is relatively little empirical evidence on the function of corridors for specific wildlife species (Beier and Noss 1998). Simberloff (1994) stresses that current theory on the usefulness of corridors is an inadequate substitute for intensive field studies. While corridor proponents have argued that there is an effect of fragmentation on local populations (Lord and Norton 1990; Fahrig and Merriam 1993; Fahrig 1997), they have only focused on principles that (in theory) aim to remedy the effects of fragmentation. Unfortunately, there is little empirical evidence that supports or refutes the notion (Robinson et al 1992; McCoy and Mushinsky 1994; Hinsley et al. 1996; Gaines et al. 1997), particularly for carnivores. Furthermore, when exploring responses to fragmentation along a gradient (e.g. corridors), thresholds for species or populations have been dealt with theoretically (Simberloff and Cox 1987; Bascompte and Solé 1996; Schumaker 1996; Rosenberg et al 1997) rather than quantitatively (but see Downes et al. 1997; Beier and Noss 1998).

Intuitively, it would seem that those species sensitive to higher levels of urbanization and fragmentation would be more likely to avoid such areas. Few studies have evaluated how landscape factors such as urban development limit or enhance a species' distribution and abundance along a corridor or gradient of open space. Previous studies have investigated the use or avoidance of residential areas or roadways within a species' home range, but this has been limited to larger carnivores, including coyotes (Atkinson and Shackleton 1991; Quinn 1995, 1997b; Romsos 1998), bobcats (Lovallo and Anderson 1996a, 1996b; Harrison 1998), and gray fox (Harrison 1997). However, monitoring the distribution and relative abundance of these species across a gradient of development has received little, if any, attention. The first goal of this study was to gain insight on how local populations respond in distribution and relative abundance to varying levels of fragmentation along a wildlife corridor or gradient of open space.

One of the principal factors contributing to habitat fragmentation has been the construction of roadways (Meffe et al. 1997). Roadways have been identified as threats to the long-term persistence of rare and threatened species, including grizzly bears

(Gibeau and Herrero 1998; Servheen et al. 1998), black bears (Brody and Pelton 1989), gray wolves (Paquet and Callahan 1996), Florida panthers (Foster and Humphrey 1995; Land and Lotz 1996), mountain lions (Beier 1996), lynx (Ruediger 1998), ocelots (Tewes and Blanton 1998), snakes (Rudolph et al. 1998) and desert tortoises (Boarman and Sazaki 1996). Not only do these roadways separate previously connected areas of habitat, they also create a barrier effect for organisms attempting to move between patches (Jackson and Griffen 1998). A barrier effect can have detrimental impacts on local populations in that, over time, populations restricted to these patches may experience a reduction in genetic diversity due to increased inbreeding, increased risk of local extinction due to population dynamics and catastrophic events, and decreased ability to recolonize (Yanes et al. 1995). In addition, increasing highway mortality also plays a role in eliminating more individuals from a population (Harris and Gallagher 1989). Aside from fragmenting habitat, roadways also create edges that would otherwise be absent in undisturbed conditions (Reed et al. 1996).

In certain situations, particularly within an urban environment, maintaining connections between fragmented habitats may be virtually impossible, because many urbanized localities have irreversibly fragmented habitats through the construction of roadways. In fact, Adams and Dove (1989) suggest that recreation values have received greater attention than biological considerations in planning and managing linkages through urban areas. Despite the possible advantages to maintaining some degree of connectivity within an urban landscape, several factors typically associated with the urban/wildland interface may lessen the effectiveness of corridors. First, human activity may have an adverse affect on animal movement patterns (Clevenger 1998; Griffiths and

Van Schaik 1993). Second, exotic species, including domestic animals, may inhibit movement of native species. Finally, the presence of roadways may act as a mortality sink, as animals attempt to negotiate their way from one patch to another (Kline and Swann 1998).

To counteract the negative impact that roadways have on animal movement, the role of underpasses as an alternative route to surface crossings has received increasing attention (Mansergh and Scotts 1989; Foster and Humphrey 1995; Yanes et al. 1995; Rodriguez et al. 1996; Clevenger 2000). With the exception of mule deer (Reed et al. 1975; Reed 1981), most of these studies have not looked at frequency of underpass usage, as it relates to the positioning of the underpass relative to the surrounding landscape variables, or the dimensions of the underpass (Yanes et al. 1995, Foster and Humphrey 1995, Clevenger 1998, Clevenger 2000). No study has systematically investigated underpass use by a suite of mammals within an urbanizing landscape. The second goal of this study, therefore, was to analyze associations between species underpass use and variables related to the positioning of the underpass (relative to the surrounding landscape) and the dimensions of the underpass.

METHODS

Puente-Chino Hills Transects

Study Area

The Puente-Chino Hills represent a continuous series of undeveloped open spaces consisting of both private and public lands, extending west from CA Route 91 in Orange and Riverside Counties to Interstate Route 605 in Los Angeles County, California (Figure 1). This 50 km long stretch of hills is entirely surrounded by urbanization with two exceptions: the eastern end is linked to the Santa Ana Mountains (Cleveland National Forest) by the Coal Canyon Biological Corridor and the western end is physically linked to the San Gabriel Mountains (Angeles National Forest) by the San Gabriel River. The connection at the eastern end is far more intact than that at the western end, although recent development threats have jeopardized the eastern linkage. Coal Canyon extends almost 3 km from Cleveland National Forest to the Santa Ana River, Featherly Regional Park, and Chino Hills State Park (Figure 2). While a majority of the habitat is still intact between these locales, development pressure has threatened to sever this connection.

The western connection is comprised of a 20 km stretch of the San Gabriel River, the majority of which is channelized and lacks vegetation. Therefore, it is highly unlikely that the San Gabriel River is a viable connection between the San Gabriel Mountains and the western Puente Hills. Due to the extreme separation of the western end from a core area, the Puente-Chino Hills, at a regional scale, more closely resemble a peninsula of habitat extending from the Santa Ana Mountains into the urban matrix of the Los Angeles Basin. On a local scale, however, the open space connecting Chino Hills State Park with the Whittier Hills does represent a potential animal movement corridor.

Aside from connections to the Santa Ana and San Gabriel Mountains, additional patches of open space are located near the Puente-Chino Hills and include the San Jose Hills and the Prado Flood Control Basin (Figure 1). The San Jose Hills are separated from the Puente Hills by CA Route 60 and the Prado Flood Control Basin is separated from the eastern Chino Hills by CA Route 71. While these areas are not contained within the linear east-west series of connected open spaces, they represent additional blocks of habitat that harbor local populations of plant and animal species. Although sampling did not occur in the San Jose Hills, surveys were conducted within the Prado Flood Control Basin in conjunction with the CA Route 71 Carnivore Telemetry Project (Lyren in prep).

The Puente-Chino Hills corridor is widest at Chino Hills State Park, where it stretches almost 9 km across Orange, Riverside, and San Bernardino Counties (Figure 2). Further west, at Harbor Blvd., it narrows to a 1.5km wide area of open space (Figure 3). From Harbor Boulevard to Colima Road, the average width of the corridor is approximately 1 km. In the Whittier Hills, the width of open space widens to almost 3 km (Figure 3). The western end of the hills is bordered by Workman Mill Road in the vicinity of Interstate Route 605.

The entire study area was divided into seven sections. Each section was separated from adjacent sections by major roadways (Figures 2 and 3):

1. CA Route 91 to Carbon Canyon Road (CA Route 142), including CA Route 71 and Prado Flood Control Basin
2. Carbon Canyon Road (CA Route 142) to CA Route 57
3. CA Route 57 to Harbor Boulevard
4. Harbor Boulevard to Hacienda Boulevard
5. Hacienda Boulevard to Colima Road
6. Colima Road to Turnbull Canyon Road
7. Turnbull Canyon Road to Workman Mill Road

Sampling Techniques

Several sampling techniques were used to document distribution and relative abundance for the target species in each section: 1) track surveys, 2) scat surveys, and 3) remotely triggered camera surveys. From each of these surveys, an index of relative abundance was calculated for each species. Target species included mountain lion (*Puma concolor*), mule deer (*Odocoileus hemionus*), coyote (*Canis latrans*), bobcat (*Felis rufus*), gray fox (*Urocyon cinereoargenteus*), raccoon (*Procyon lotor*), striped skunk (*Memphitis memphitis*), long-tailed weasel (*Mustela frenata*), and the non-native Virginia opossum (*Didelphis virginiana*), domestic cat (*Felis catus*), and domestic dog (*Canis familiaris*). Sampling locations were selected based on access and represented city, county, and state lands, including utility rights-of-way.

Track Surveys

Scent stations have been widely used as a means to monitor trends in carnivore populations. Following methods developed by Linhardt and Knowlton (1975), many studies have attempted to validate this method as an accurate means of determining abundance and trends of carnivore populations (Hatcher and Shaw 1981; Clark and Campbell 1983; Conner et al. 1983; Woelfl and Woelfl 1997; Sargeant et al. 1998). Despite the numerous attempts to relate the number of carnivore visits to scent stations as a measure of carnivore abundance, many discrepancies still exist as to how these methods can be standardized. Several studies have argued the importance of transect interval, station interval within a transect, type of station substrate, type of scent lure or bait, and the number of sampling nights (Roughton and Sweeny 1982; Sargeant et al. 1998). Recognizing these limitations, track surveys have been shown to be effective measures of distribution and relative abundance of mammalian species (Conner et al. 1983; Sargeant et al. 1998). For this study, track survey methodology followed that of Crooks (1999) in San Diego and Orange Counties, thus allowing regional comparisons of indices without inconsistencies in methodology.

Forty-two track transects were established along dirt roads and wildlife trails throughout the corridor. Scent stations were established along 1000 m transects with five stations at approximately 250 m intervals. In cases where a roadway was the transect (e.g. Carbon Canyon and Turnbull Canyon), stations were placed at roadside pullovers or where drainages crossed the roadway. Although each transect generally consisted of five stations, due to constraints on sampling area some transects contained fewer stations. In addition, 13 individual track stations, not part of continuous track transects, were placed throughout the corridor in areas where access was limited and/or a complete transect was not feasible. These stations were established to document crossing locations of species at critical choke points.

Each scent station consisted of a 1 m^2 plot of finely sifted gypsum powder and a rock, placed in the middle of the station, baited with two artificial scent lures every other day (Russ Carman's Pro Choice and Canine Call). Stations were checked for visitation for five consecutive mornings. Several studies argue that one night of sampling is sufficient (Roughton and Sweeny 1982; Conner et al. 1983; Woelfl and Woelfl 1997; Sargeant et al. 1998). However, other studies sampled from two days (Hatcher and Shaw 1981) to at least five consecutive days (Martin and Fagre 1988; Hein and Andelt 1994; Heske 1995). Studies sampling for only one day were those that documented the presence/absence of coyotes, a relatively common species. By sampling for five consecutive days, those species occurring at lower densities, or those whose probability of detection is low due to natural habits, were more likely to be detected. If an animal visited a station, tracks were identified to species and the station was cleared and resifted.

Scent stations were surveyed during the summer (June-August) and fall (September-November) seasons of 1997 and 1998. Some transects were surveyed an additional season during the winter of 1997/1998 (December-February). Rains during the winter and spring seasons made track surveys difficult to execute, as the gypsum powder was not usable when wet.

To obtain an index of relative abundance, the number of visits by each species was divided by the total sampling effort. This index was calculated using the following equation:

$$I = \{v_j/(s_j n_j)\}$$

where, I = index of carnivore activity at transect j

v_j = number of stations visited by species at transect j

s_j = number of stations in transect j

n_j = number of nights that stations were active in transect j

Any scent station in which tracks were too difficult to read was omitted from the sampling night. Thus, the true sampling effort was:

$$\{s_j n_j\} - o_j$$

where, o_j = number of omits in transect j

This index does not provide data on the absolute number of individuals. Instead, the index is used to compare relative abundance of species across space and time (Conner et al. 1983; Sargeant 1998). Track indices were pooled across seasons to derive a single track index per transect for each individual species. These indices served as the measure of relative abundance in the statistical analysis of the transect data.

Scat Surveys

Scat surveys, relative to track surveys, have received little attention as a useful technique for documenting carnivore abundance. Techniques in this study followed those used by U.S. Department of Agriculture Animal Damage Control (Kelly 1994) and by local researchers (Crooks 1999).

Thirty-two scat transects were established along dirt roads and wildlife trails throughout the corridor. Scat surveys, conducted for coyote, bobcat, and fox, sampled the same stretch of roads or trails as track surveys and were conducted during the summer/fall seasons of 1997 and 1998. Transects were cleared of all scat following termination of track surveys. Two collections were made at 2 and 4 weeks after the initial clearing. Each scat was identified to species and ranked on a confidence scale of 1 to 3, with 3 being the highest confidence level of species identification. Those scat which were rated 2 and 3 were included in the analysis.

The index of relative abundance was calculated using the following equation:

$$I= \{s_j/m_j/d_j\}$$

where, I = index of carnivore activity at transect j

s_j = number of scats collected from transect j

m_j = length of transect j

d_j = number of days during which scats were deposited at transect j

This index does not provide data on the absolute number of individuals. Instead the index is used to compare relative abundance of species across space and time.

Scat indices were not included in the statistical analysis of relative abundance for several reasons. Unlike indices from track surveys, scat indices were obtained for only three species (coyote, bobcat, and gray fox). Because many of the scat were either driven over or weathered, few could be given a confidence ranking of 2 or 3 and, thus, the sample size was small. Also, Spearman rank correlation analysis indicated that track indices, which were not normally distributed, were correlated with scat indices for coyotes ($r_s = 0.48$, $p < 0.01$, $n = 30$) and bobcats ($r_s = 0.76$, $p < 0.001$, $n = 30$), but not for gray fox ($r_s = 0.04$, $p > 0.05$, $n = 30$). Thus, track surveys were used in the statistical analysis, and scat surveys were used only to confirm the presence or absence of a species at each transect.

Camera Surveys

Remotely triggered cameras have increasingly become a useful tool in recording activity of various wildlife species (Griffiths and Van Schaik 1993; Jacobson et al. 1997; Karanth and Nichols 1998). Cameras provide a relatively low-maintenance means of surveying wildlife populations because visitations to the units are only made to change film and batteries.

Camtrak cameras (Camtrak South Inc, 1050 Industrial Drive, Watkinsville, GA 30677) were used to complement track and scat surveys. Cameras were placed along scat and track transects wherever the probability of theft was low. Otherwise, cameras were placed along a wildlife trail or a portion of a streambed paralleling the track/scat transect in order to reduce its detectability by humans. Each pass of an animal by the infra-red sensor triggered the camera. Date of pass, and in some instances time of day, were recorded on each print. Cameras were operated during the summer and fall seasons of 1997.

To obtain an index of relative abundance, the number of visits by each species was divided by the total sampling effort. This index was calculated using the following equation:

$$I= \{v_j/n_j\}$$

where, I = index of carnivore activity at camera j

v_j = number of passes by species at camera j

n_j = number of nights that camera j was active

Theft was a problem at several locations throughout the study area. As a result, only five cameras were maintained along track/scat transects. Therefore, as with the scat surveys, camera survey results were used only to confirm the presence or absence of species at various locations throughout the corridor.

Landscape Variables

Track indices for each species were correlated with five landscape variables: % wild, % residential, % urban park, road density, and corridor width. Each variable was measured within a 5 km radius of the center of each transect. Percent wild was the proportion of open space surrounding the transect. Percent residential was the proportion of residential development surrounding the transect. Percent urban park was the proportion of developed park land (including city parks and golf courses) surrounding the transect. Road density was the number of roads surrounding the transect. Corridor width was the total length of continuous open space on opposites sides of the transect.

Statistical Analysis

Three variables (% wild, % residential, and % urban park) were arc-sine transformed and all other variables (track indices, corridor width, and road density) were log-transformed. Of the dependent variables, only striped skunk indices did not fit a normal distribution after the logarithmic transformation. Independent variables not fitting either a normal or lognormal distribution included corridor width and road density. As a result, the non-parametric Spearman rank correlation test was performed for all variables so that testing would remain consistent.

The landscape variables analyzed showed a high degree of correlation with each other (Table 1). Spearman rank correlation analysis indicated that corridor width was positively correlated with % wild and negatively correlated with % residential and road density. There was a negative correlation between % wild and % residential, % urban park, and road density. Road density was positively correlated with % residential and % urban park. To reduce the dimensionality of the independent variables, four of the landscape variables (% wild, % residential, corridor width, and road density) were analyzed through Principal components analysis (PCA). The purpose of this was to derive a component that was a weighted combination of the input variables (Kachigan 1991). Percent urban park was not included in the analysis since it was not correlated with all four variables. The first ordination produced an eigenvalue of 3.29 (% trace = 82.13) with the component representing corridor quality. Narrow portions of the corridor had high % residential, high road density, and low % wild, contrasted with wide portions of the corridor consisting of high % wild, low % residential, and low road density. Thus, species indices correlated with the positive end of the axis were those associated with low corridor quality whereas species correlated with the negative end of the axis were associated with high corridor quality. This new variable was termed fragmentation and was correlated against track indices for each species.

Each variable was correlated against species visits to transects in order to determine if there was an association between the probability of a species occurring at a transect (logistic regression analysis) and the relative abundance of a species at a transect (Spearman Rank Correlation). Probability was defined as whether or not the species ever visited the transect. Relative abundance was defined as how often the species visited the transect (as expressed in the track index).

To determine if the probability of detecting a species correlated with a particular landscape variable, transects were grouped into those that were visited by a species and those that were not. Logistic regression analysis was performed to see if the probability of detecting a species at a transect was predicted by any of the five landscape variables, as well as the fragmentation variable.

To determine if the relative abundance of each species was associated with a particular landscape variable, track indices were correlated with the landscape variables using the Spearman rank correlation. Correlations between relative abundance and landscape variables were conducted twice for each species. First, all transects were included in the analysis. Second, those transects that were never visited by a species were excluded from the analysis. This second analysis allowed evaluation of the effect of landscape variables on the relative abundance of transects actually visited by a species.

Relative Abundance of Species Across the Puente-Chino Hills

Track indices for species were plotted from east to west so that relative abundance could be compared along the corridor. For each species, track indices were averaged for each section by summing the index for each transect and dividing by the total number of transects in that section. It should be noted that the number of transects within a section is a function of that section's size; therefore, larger sections contained more transects. This could cause a higher variability around the mean track index in smaller sections. Also, some sections were not sampled in their entirety due to access limitations (Sections 3 and 6; Figure 3). As a result, transects did not sample the entire section, and therefore provide indices for only a portion of that section. However, these graphs (Figures 4-13) serve to illustrate relative abundance of species throughout the corridor.

Underpass Surveys

Underpasses

Eleven roadways of varying widths bisect the corridor (Figures 2 and 3). The easternmost roadway, CA Route 91, separates the Santa Ana Mountains and Chino Hills State Park. To the northeast, CA Route 71 separates the Chino Hills and the Prado Flood Control Basin. Continuing west, the corridor is bisected by Carbon Canyon Road (CA Route 142), CA Route 57, Brea Canyon Road, Harbor Boulevard, Fullerton Road, Hacienda Boulevard, Colima Road, Turnbull Canyon Road, and Workman Mill Road/Interstate Route 605. These roadways represent potential barriers to wildlife movement across the corridor, as they have fragmented the remaining open space into nine patches of varying sizes.

Any mammal species attempting to cross a roadway from an adjacent fragment would have two options: an at-grade, or surface, crossing or utilizing an underpass. While it is difficult to determine where animals are making at-grade crossings, several track transect or individual scent stations attempted to document potential crossing locations. Individual scent stations were placed along several roadways, including Brea Cutoff Road, Fullerton Road, and Colima Road. Track transects were established along Carbon Canyon Road and Turnbull Canyon Road.

Underpasses are easier to monitor and provide a safe alternative to at-grade crossing attempts. Three types of underpasses were monitored: highway bridges, tunnels, and culverts. Highway bridges include any open span. Tunnels are defined as those underpasses designed for equestrian, vehicular, or wildlife uses. Culverts refer to any underpass that is primarily designed for drainage purposes. Forty-three underpasses were monitored including two highway bridges, nine tunnels (including three wildlife tunnels, three vehicle service tunnels, and three equestrian tunnels), and 32 culverts.

Sampling Techniques

Underpasses were monitored using two methods. First, remotely triggered cameras were stationed at the entrances to underpasses. These cameras were secured to a wooden stake driven into the ground. The stake and camera were placed along the headwall of the underpass at a distance of 1 m from the culvert entrance. Film and batteries were checked at least every two weeks, with more frequent camera maintenance occurring at underpasses with higher wildlife activity. As described in the Camera Surveys section above, species usage was determined by dividing the number of pictures of each species through the underpass by the number of nights the camera was active. Species direction of travel and time of pass also were recorded.

A second method used to monitor underpass usage was sifting gypsum powder across the floor of the underpass. Tracks left by individuals passing through the underpass were identified to species. Direction of travel also was recorded. Species usage was recorded as the number of times a given species used the underpass divided by the number of days the underpass was sampled.

Species usage of each underpass was recorded through three different indices: an index for species recorded at underpasses monitored by track stations, an index for species recorded at underpasses monitored by cameras, and an index for species recorded at underpasses that were monitored by both track and camera stations. A paired sample t-test revealed no difference in index values for pooled species obtained by either track or camera methods ($t = 1.80$, $p > 0.05$, $df = 209$). Therefore, index values obtained by combining both methods were used in the statistical analyses. This combined index was calculated by dividing the number of visits detected by camera and/or track surveys at an underpass, divided by the number of days the underpass was sampled. This combined index was not different from track ($t = 1.72$, $p > 0.05$, $df = 209$) or camera ($t = 1.44$, $p > 0.05$, $df = 209$) indices, and therefore was used in subsequent statistical analyses.

<u>Landscape and Dimension Variables</u>

Five landscape variables and nine underpass characteristics were measured to describe each roadway underpass. Landscape variables were the same variables measured for the transect analysis: % wild, % residential, % urban park, road density, and corridor width. Each landscape variable was measured within a 1 km radius from the underpass. Underpass dimension variables included length, width, height, and openness. Underpass length was the distance an animal had to travel to successfully pass through the underpass. Width was defined as the distance between each wall of the underpass. Height was defined as the distance from the top to the bottom of the underpass. Openness was defined as width x height/length (Yanes et al 1995). Percent natural cover was the proportion of natural vegetation within a 100 m radius of the underpass entrance. Percent landscape cover was the proportion of landscaped vegetation within a 100 m radius of the underpass entrance. Percent cover for each vegetation type (natural and/or landscaped) was estimated at both underpass entrances and averaged to yield one value per underpass. Both % natural cover and % landscape cover are hereafter referred to as dimension variables.

Two categorical variables also were measured for each underpass. Fencing defined the type of fencing along the roadway and was divided into three categories: 8-foot high chain link, barbed wire, or no fencing. Divider defined the type of barrier on the roadway above the underpass and was placed into three categories: concrete wall, guardrail, or no barrier. Analysis of fencing and divider type on underpass usage was only conducted for underpasses along CA Route 71. This was done to eliminate any confounding effects of landscape variables on underpass usage.

Statistical Analysis

Five variables (% natural cover, % landscape cover, % wild, % residential, and % urban park) were arc-sine transformed and all other variables (all track/camera indices, corridor width, and road density) were log-transformed. All of the dependent variables (track indices) fit a normal distribution after transformation. However, none of the independent variables were normalized with these transformations. As a result, the non-parametric Spearman rank correlation test was performed for all variables.

Both landscape and dimension variables showed a high degree of covariation (Tables 2 and 3). As with the transect analysis above, corridor width at an underpass was positively correlated with % wild and negatively correlated with % residential and road density. There was a negative correlation between % wild and % residential and road density. A positive correlation existed between % residential and road density (Table 2). Dimension variables also were highly correlated with each other (Table 3). Height was positively correlated with width and openness. Openness was also positively correlated with height and negatively correlated with length.

A PCA was conducted on the same four landscape variables (% wild, % residential, corridor width, and road density) factored out in the transect analysis. The values of these variables differed from those in the transect analysis in that they were measured within a 1 km radius from the underpass. The ordination of the these landscape variables produced an eigenvalue of 2.99 (% trace = 74.69) with the first component representing corridor quality. Narrow portions of the corridor had high % residential, high road density, and low % wild, contrasted with wide portions of the corridor which had high % wild, low % residential, and low road density. Thus, species indices correlated with the positive end of the axis were those associated with low corridor quality whereas species correlated with the negative end of the axis were associated with high corridor quality. This new variable was termed fragmentation and was correlated against each dependent variable.

The ordination of dimension variables (length, width, height, and openness) produced an eigenvalue of 3.04 (% trace = 75.92) with the first component representing underpass size. Longer underpasses were lower in height, width, and openness, contrasted with shorter underpasses consisting of greater height, width, and openness. Thus, species indices correlated with the positive end of the axis were those associated with using short and more open underpasses whereas species correlated with the negative end of the axis were associated with long, less open underpasses. This new variable was termed underpass size.

Spearman rank correlation analysis indicated that fencing type was significantly correlated with divider type ($r_s = 0.89$, $p < 0.001$, $n = 43$). This was almost certainly due to the design of underpasses along CA Route 71. On this freeway, 8-ft high chain link fencing generally complemented concrete roadway barriers, and barbed wire fencing was placed along stretches of the roadway divided by a guardrail.

Only underpasses where a species was recorded (through track, scat, or camera surveys) on both sides of the roadway were used in the analyses. Thus, only those underpasses that could be potentially used by each species were included in the analysis. Both long-tailed weasels and domestic cats failed to meet this criterion. Weasels were only documented on both sides of one roadway (CA Route 71). Domestic cats were only recorded in Section 5.

Each underpass was classified into those that were used by a species and those that were not, and a logistic regression was conducted to determine if any underpass or landscape variables predicted the probability of species usage. To determine if the frequency of use was associated with any of the landscape or dimension variables, a Spearman rank correlation test was used. Spearman correlations between frequency of underpass use and landscape/dimension variables were conducted twice for each species. First, all underpasses were included in the analysis. When including all underpasses, the results are partially due to the distribution, or probability of occurrence, of species across the corridor. Second, those underpasses that were never visited by a species were excluded from the analysis. This second analysis therefore allowed another means of determining more fully the effect of landscape/dimension variables on the frequency of use of underpasses actually visited by a species.

For each categorical underpass variable, a contingency table was used to determine if a specific type of underpass category was used more or less frequently than other types of underpass categories. If assumptions of the contingency table were violated, the Roscoe and Byers rule was used to determine if sample size was sufficient (Zar 1984).

RESULTS

Puente-Chino Hills Transects

<u>Probability of Occurrence at Transects</u>

Landscape variables predicted the probability of occurrence (hereafter defined as probability) for seven species (Table 4). Logistic regression analysis indicated that bobcat probability was positively predicted by % wild and corridor width and negatively predicted by road density. Weasel probability was positively predicted by % wild and negatively predicted % residential and road density. The % urban park positively predicted opossum probability of occurrence and % wild positively predicted raccoon probability of occurrence. Mule deer probability was positively predicted by % residential and road density and negatively predicted by corridor width. The probability of domestic dog occurrence was positively predicted by % urban park and negatively predicted by % wild and corridor width. Domestic cat probability was positively predicted by % residential and road density and negatively predicted by % wild and corridor width.

Probability of occurrence of five species was associated with the fragmentation variable generated from the PCA (Table 4). Fragmentation was positively associated with the probability of mule deer, domestic dog, and domestic cat occurrence. Species whose probability of occurrence was negatively correlated with fragmentation were bobcat and weasel.

Relative Abundance at Transects

Track indices were correlated with landscape variables to determine if there was an association between the relative abundance and landscape variables (Table 5). When all of the transects were analyzed, the relative abundance of seven species was associated with the landscape variables. Bobcat relative abundance was positively correlated with % wild and corridor width and negatively correlated with % residential and road density. Weasel relative abundance was positively correlated with % wild and negatively correlated with % residential and road density. Striped skunk abundance was negatively correlated with corridor width and raccoon abundance was positively correlated with % wild. Mule deer relative abundance was positively correlated with % residential and negatively correlated with corridor width. Domestic dog relative abundance was positively correlated with % residential and road density and negatively correlated with % wild and corridor width. Domestic cat relative abundance was positively correlated with % residential and road density and negatively correlated with % wild and corridor width.

When including in the analysis only transects that species visited, only striped skunk and opossum showed a significant response to the landscape variables (Table 5). Striped skunk track indices were negatively correlated with corridor width and % wild and positively correlated with % urban park and road density. Opossum abundance was negatively correlated with % residential and road density.

Track indices of some species were also correlated with the fragmentation variable generated from the PCA (Table 5). Species showing a positive correlation between frequency and fragmentation included mule deer, domestic dog, and domestic cat. Species showing a negative correlation between frequency and fragmentation included bobcat and weasel. When analyzing only those transects where a species occurred, striped skunk and domestic dog were both positively correlated with fragmentation.

<u>Relative Abundance of Species Across the Puente-Chino Hills</u>

Coyote abundance was evenly distributed throughout the entire corridor (Figure 4). Relative abundance peaked around Harbor Boulevard and was lowest west of Turnbull Canyon Road. Overall, the average coyote abundance for each section ranged between 0.310 and 0.521.

Bobcat abundance peaked on both the eastern and western portions of the corridor (Figure 5). Sections 2 and 6 had equal average indices (0.088) and represented the highest level of abundance within the Puente-Chino Hills. Sections 3, 4, and 5 showed dramatically lower abundance values.

Relative abundance of gray fox peaked at the eastern and western portions of the corridor (Figure 6). These peaks occurred in Sections 2 and 4 and 5, with Section 5 having the highest average relative abundance levels. Average indices were lower in Sections 1, 3, 6, and 7 and ranged between 0.031 and 0.042.

Although scent stations did not target deer, their average indices in each section were plotted (Figure 7). Section 6 had the highest average relative abundance of all sections (0.110). Average indices varied between 0.010 and 0.041 for Sections 2 through 5. The lowest average indices were in sections 1 and 7. This does not mean that deer were not present in these sections, but rather that they did not visit scent stations in these sections.

Opossum abundance varied between 0.026 to 0.036 in Sections 1 through 4 (Figure 8). Sections 5 and 6 showed lower indices. Average relative abundance was highest in Section 7 (0.049).

The average index for raccoons peaked in Section 5 (0.061) but was lower throughout the remainder of the corridor (Figure 9). Average abundance in the other sections was never greater than 0.021.

Striped skunk abundance also peaked in the middle of the corridor (Figure 10). Section 5 had the highest average index and combined with Section 4, displayed the highest abundance of skunks throughout the entire corridor (0.163 and 0.199 for Section 4 and 5, respectively). The remaining sections had average indices between 0.038 and 0.104.

Long-tailed weasels were only detected in Section 1 (Figure 11). The average index in that section was 0.003.

Domestic dog abundance peaked between Sections 4 and 5 (Figure 12). Average relative abundance in these two sections was 0.360 and 0.512, respectively. Abundance was lowest in the eastern half of the corridor, with indices averaging between 0.046 and 0.160. Average indices dropped in Section 6 (0.149), but increased to 0.326 in Section 7.

Finally, domestic cats were only detected in Section 5 (Figure 13). Relative abundance at the two transects where this species was recorded was 0.014 and 0.016.

Underpass Analysis

Probability of Species Using Underpasses

Landscape (Table 6) and underpass dimension (Table 7) variables predicted the probability of underpass usage (hereafter defined as probability) for eight species. Bobcat probability was positively predicted by % natural cover and % wild and negatively predicted by % landscape cover, % residential, and road density. Weasel probability was positively predicted by % wild and corridor width and negatively predicted by % residential and road density. Coyote probability was positively predicted by corridor width and negatively predicted by % residential. Gray fox probability was positively predicted by underpass width, height, openness, and % natural cover and negatively predicted by underpass length and corridor width. Mule deer probability was positively predicted by underpass height and openness and negatively predicted by corridor width. Opossum probability was positively predicted by % landscape cover and % urban park. Raccoon probability was negatively correlated with corridor width. Striped skunk probability was positively predicted by % urban park. Domestic cat probability was positively predicted by % residential and road density and negatively predicted by % wild.

Four species showed an association between probability of using an underpass and the fragmentation variable calculated from the PCA (Table 6). Only domestic cat probability showed a positive correlation with fragmentation. Species whose probability was negatively correlated with fragmentation were bobcat, coyote and weasel.

Only gray fox showed a positive correlation with probability of usage and the underpass size variable as represented by the factor analysis (Table 7).

Frequency of Species Using Underpasses

When analyzing all of the underpasses collectively, eight species showed an association between frequency of use and the landscape (Table 8) and dimension (Table 9) variables. Bobcat frequency of use of underpasses was positively correlated with % natural cover and % wild and negatively correlated with % residential and road density. Coyote frequency of use of underpasses was positively correlated with underpass openness and corridor width. Weasels were only detected on both sides of CA Route 71, therefore frequency of underpass usage was only performed on underpasses along CA Route 71. There were no associations between any of the landscape variables and the frequency of underpass use by weasels, a result largely due to the lack of variation of each variable (for example, corridor width did not vary). Gray fox frequency of use of underpasses was positively correlated with underpass width, height, openness, % natural cover and negatively correlated with underpass length and corridor width. Mule deer frequency of use of underpasses was positively correlated with underpass width, height, and openness. Raccoon frequency of use of underpasses was positively correlated with underpass height and negatively correlated with corridor width. Domestic cats were only detected by track transects in one section. Therefore, no analysis was conducted.

When analyzing only those underpasses that were used by each species, several additional factors were associated with the frequency of use (Tables 8 and 9). Bobcats used underpasses more frequently as underpass width increased and less frequently as corridor width increased. Coyotes used underpasses more frequently as underpass width and height increased. Coyotes were also more frequent at underpasses surrounded by higher levels of % residential, % urban park, and road density and less frequent at underpasses surrounded by higher levels of % wild. Opossums were more frequent at longer underpasses and raccoons were more frequent at wider underpasses. Striped skunks were more frequent at underpasses that were surrounded by higher levels of % residential and less frequent at underpasses surrounded by higher levels of % wild and located in wider portions of the corridor (Tables 8 and 9).

Frequency of use of underpasses was also correlated with the factor scores from the ordination analysis of the underpass variables and landscape variables. When all of the underpasses were analyzed, the fragmentation factor was positively correlated with domestic cat frequency and negatively correlated with bobcat frequency (Table 8). Gray fox showed a positive association with underpass size (Table 9).

When taking into account only those underpasses that were used by a particular species, the fragmentation factor was positively correlated with bobcat frequency, coyote frequency, opossum frequency, raccoon frequency, and striped skunk frequency (Table 8).

Effects of Fencing and Roadway Dividers on Species Usage

The presence of a fence along CA Route 71 was a significant factor determining usage for coyotes. Coyote use of underpasses was associated with the type of fencing above the underpass ($x^2 = 6.01$, $p < 0.05$). Barbed-wire fencing and 8-ft high chain link fencing were combined into one category (fence) and analyzed against underpasses with no fencing. Although it was not significant, coyotes used underpass with fencing above them greater than expected ($x^2 = 2.59$, $p = 0.109$). Fencing was not a significant factor for any other species usage of underpasses along CA Route 71.

The type of divider along CA Route 71 was a significant factor influencing coyote usage of underpasses ($x^2 = 12.53$, $p < 0.01$). When combining divider types into divider (guard rail and cement barrier) and no divider, coyotes used underpasses with a divider above them more than expected ($x^2 = 11.67$, $p < 0.01$). Striped skunk usage of underpasses along CA Route 71 was also associated with the type of barrier along the freeway ($x^2 = 14.53$, $p < 0.001$). When combining divider types, skunks used underpasses with a divider above them more than expected ($x^2 = 14.00$, $p < 0.001$).

DISCUSSION

Distribution and Relative Abundance of Species Across the Puente-Chino Hills

Landscape variables predicted the probability of occurrence or relative abundance of eight of the 10 target species at transects across the Puente-Chino Hills. Species that were more sensitive to the effects of fragmentation (negative correlations with % park, % residential and road density and positive correlations with corridor width) were those that are commonly associated with wild habitats. Those species that are less sensitive to the effects of fragmentation (negative correlation with % wild and corridor width) showed an increased probability to occur at scent stations closer to urbanized localities.

Obviously, the landscape variables analyzed in this study are not the only factors that contribute to the probability of occurrence or relative abundance of a species at a site. Perhaps a stronger predictor is the actual habitat type and quality of habitat surrounding the transects. However, the condition of these habitats may result from being in close proximity to urbanized areas. For example, a species associated with a particular habitat may not be found in the narrow portion of the corridor if that habitat is not there. In many situations along an urban-wildland interface, or a disturbed-undisturbed interface, edge effects may extend well into the wildland habitat adjacent to the disturbed location (Murcia 1995). In fact, Noss and Csuti (1997) point out that the pervasiveness of edge effects may result in habitat patches below a certain size lacking true core habitat upon which certain species are dependent. The same may hold true for corridors: as corridors get narrower, habitat necessary for interior dwelling species may be lacking. Therefore, corridor width may serve as an appropriate variable when considering the quality of habitat surrounding a transect.

Species Sensitive to Fragmentation

Bobcats showed a strong sensitivity to corridor effects, as both the probability of occurrence and relative abundance were negatively correlated with the fragmentation factor. Bobcats were associated with portions of the corridor that were wider and contained greater areas of wildland and lower densities of roads.

Although % residential was not a significant factor determining bobcat probability, it was negatively associated with bobcat abundance. This indicates that while bobcats may occur in close proximity to residential areas, they do so less frequently when compared to areas with lower levels of % residential. Harrison (1998) also reported bobcats entering residential areas, possibly to prey on rodents, birds, or small pets. However, sightings by residents were clustered adjacent to the nearest block of undeveloped habitat (Harrison 1998), supporting my conclusions that wild areas must be present in order to support resident bobcat populations.

Road density was negatively correlated with both bobcat probability and abundance. Bobcats in Wisconsin used home ranges with low densities of secondary highways, and survival of populations may be affected by high levels of road density (Lovallo and Anderson 1996). Forman and Alexander (1998) suggest that areas of low road density may be the best indicator of suitable habitat for large vertebrates.

Although bobcats were detected within narrow portions of the corridor, these narrow sections might be serving as movement corridors to larger blocks of habitat. Bobcat persistence likely depends on the ability to successfully disperse to adjacent wildlands. This could be a cause of concern for bobcat persistence in the Puente-Chino Hills, as narrow portions of the corridor are currently demonstrating a negative impact on bobcat abundance. Such opportunities for dispersal could be limited if the remaining wildland is encroached upon by development. Although this study did not address specific movements of individual bobcats throughout the corridor, bobcats at the eastern end of the corridor travel in excess of 5 km (Lisa Lyren, pers. comm.). However, these travel distances were restricted to the widest portion of the corridor (Section 1).

The sensitivities of bobcats to narrow portions of the corridor reflect their sensitivities to residing in close proximity to urban areas. These sensitivities are not exclusively due to corridor width; rather they are incorporated into the effects of fragmentation on wildlife communities. As mentioned before, edge effects may extend so far into the wildlands that a true core habitat is non-existent. In narrow portions of the corridor, the quality of habitat that bobcat probability and abundance depend on may be lacking. This does not imply that bobcats never travel through these areas; rather they do so less frequently when compared to larger areas of habitat. Given the sensitivities of bobcats to fragmentation, they represent an excellent target species for conservation within the Puente-Chino Hills.

Long-tailed weasel probability and abundance were negatively correlated with the fragmentation factor. In fact, weasels were only documented in the largest fragment of the study area (Section 1). Because weasels were only detected in two transects, low sample size limited the ability to evaluate differences in relative abundance at transects where weasels were detected. Furthermore, associations between the probability of weasel occurrence and the landscape variables were based on occurrence at only two transects. Therefore, the strength of the association between the landscape variables and weasel probability of occurrence is limited by the biology of the organism.

While there has been little, if any, research investigating the effects of fragmentation on weasel populations, they experience wide fluctuations in home range size relative to prey density. Home ranges averaged 24.2 ± 11.9 ha in years with low rodent densities and increased up to seven times larger (166.6 ± 69.6 ha) in years of high rodent densities (Jedrzejewski et al. 1995). In addition, weasel home range in areas of continuous forest were approximately circular, with a maximum diameter of 1457 m in years with high rodent densities. Based on this, narrow portions of the corridor may not provide adequate area for weasels to occupy.

Raccoons were not associated with the fragmentation factor, but their probability and abundance were positively correlated with % wild. Raccoons are typically associated with areas close to water (Kaufmann 1982) and particularly associate with habitat containing snags (Kennedy et al. 1991). Since these snags are generally found along riparian areas, as opposed to hillsides of coastal sage scrub or grassland habitat, it is likely that raccoons would frequently utilize riparian woodlands. In fact, raccoons have been reported to avoid open, grassy areas (Fritzell 1978, Pedlar et al. 1997). Kennedy et al. (1986) found higher densities of raccoons occurring near large areas of permanent water as opposed to drier uplands. In many urban settings throughout southern California, development has been restricted to hillsides or mesas bordering riparian areas, thus creating riparian strips bordered on both sides by development. In the Puente-Chino Hills, such networks of riparian areas are few, and those that do occur are generally removed from proximity to urban development. Therefore, raccoons prefer specialized habitats, which in the Puente-Chino Hills, unlike other areas throughout southern California, occur in less developed areas.

Species Associated with Fragmentation

Other species demonstrated a positive correlation between relative abundance and the fragmentation factor. Domestic cat and domestic dog probability and abundance were positively associated with fragmentation. While this seems intuitive, the biological implications of domestic species frequenting wildland areas adjacent to urban areas may be disastrous. Domestic cat probability and abundance were positively correlated with % residential, road density, and fragmentation and negatively correlated with % wild and corridor width. Cats, like weasels, were only detected at 2 transects. However, unlike weasels, they were detected at transects surrounded by higher levels of residential. The concentration of cats in open space areas adjacent to residential areas has negative impacts on native species. Crooks and Soulé (1999) estimated that approximately 35 hunting, outdoor cats surrounded a habitat fragment bordered by 100 residences. The impact on native species is that free-ranging cats show no response to shifts in prey density and continue to kill prey even when prey populations are low (Coleman and Temple 1993). In fact, of all the rodents, birds, and lizards returned by domestic cats to residences bordering habitat fragments in San Diego, 67%, 95%, and 100% were native species, respectively (Crooks and Soulé 1999).

The relationship between domestic dog relative abundance and the landscape variables was similar to that of domestic cats. Probability of occurrence, however, was only positively associated with the fragmentation factor and negatively associated with % wild and corridor width. While dogs are not the recreational hunters that cats are, their presence may have an adverse effect on native species. In fact, Harrison (1998) noted that bobcat sightings near houses were lower in areas with free-ranging domestic dogs. Although there was no significant association between domestic dog and bobcat track indices, their average track indices were inversely related in sections throughout the Puente-Chino Hills (Figure 14).

Mule deer probability and abundance were positively associated with % residential and the fragmentation factor and negatively associated with corridor width. Additionally, deer probability increased in areas with increasing road density. Indeed, deer have often benefited from fragmentation and have increasingly become a problem in many urbanized localities (Noss and Cooperrider 1994). In California, development adjacent to open areas has restrained growth of deer populations as well as put them in close association with areas of high-density housing (McCullough et al. 1997). In the Midwest, white-tailed deer populations have recovered from intensive habitat modification and are now flourishing in the presence of habitat fragmentation, especially in areas of intense urbanization (Anderson 1997). However, in highly fragmented areas they occur in smaller, more isolated metapopulations that are more at risk to local extinctions. Therefore, although mule deer have adapted well to urbanized localities, their long-term persistence ultimately depends on their ability to disperse successfully.

Locally, mule deer densities were estimated at 2.3-4.6 deer/km^2 in the Santa Ana Mountains (Beier 1996). In fact, Beier and Barrett (1993) estimated lower mule deer densities in chaparral-dominated areas of the Santa Ana Mountains when compared to densities of populations occupying oak woodlands, coastal sage, and grasslands in the foothills adjacent to urban areas. Such diversity of habitat is common throughout the Puente-Chino Hills corridor.

The fragmentation factor had no association with striped skunk probability, but was positively associated with striped skunk abundance. However, this association was apparent only when considering those transects that were visited by striped skunks. Additionally, at transects where striped skunks occurred, abundance increased with increasing % urban park and road density and decreased with higher % wild and corridor width. When all of the transects were analyzed, corridor width was the only significant variable (negatively) associated with striped skunk abundance. The fact that the probability of occurrence was not associated with any of the landscape variables indicates that skunks are distributed throughout the study area. However, in narrower portions of the corridor, their abundance is greater. This might reflect higher densities of skunks in the narrow sections of the corridor. Smaller areas may yield higher index values based on more individuals concentrated in a smaller area.

Opossum probability and frequency showed no association with the fragmentation factor, but their probability of occurrence was positively correlated with % urban park. Abundance was negatively associated with % residential and road density but this was only evident at transects where opossums occurred, not all transects. As with striped skunks, these variables did not predict the probability of opossums occurring at a particular site; rather they were stronger predictors of abundance at sites where opossums occurred.

Species Showing no Response to Fragmentation

Coyote and gray fox showed no response to any of the landscape variables analyzed. This does not imply that either of these species can persist in an urban or wild environment. Rather, it demonstrates that these species utilize both urban and wildland landscapes as part of their home range.

Coyotes prefer portions of their home ranges that are more associated with undisturbed habitats, but also persist in urban areas (Quinn 1995, 1997a). In Orange County, coyotes used low-density residential areas greater than expected and high-density residential areas less than expected (Romsos 1998). Coyote diet analysis has found that although they depend largely on small rodents, rabbits, fruits, and grass (Atkinson and Shackleton 1991), they also exploit human-derived foods (MacCracken 1982, Quinn 1997b). However, although they associate with urbanized areas, coyotes depend on larger areas of wildland to persist. Romsos (1998) found that coyotes were less likely to occur in developed areas unless there was open space immediately available. Crooks and Soule (1999) found that fragment size was a positive predictor of coyote abundance, indicating that minimum area thresholds likely exist for coyotes.

Harrison (1997) found that gray foxes utilized both developed and undeveloped portions of their home range, frequenting the developed portion more than expected at night and the undeveloped portion more than expected during the day. Crooks (1999) found that gray fox abundance was higher in smaller fragments. Additionally, 19.3% of gray fox scats consisted of anthropogenic food sources (Harrison 1997). Gray fox tolerance of humans appears to be minimal (Nicholson et al. 1985), but other anthropogenic factors, such as the presence of domestic dogs, may limit use of residential areas (Harrison 1993, Harrison 1997).

Summary of Species Distribution and Relative Abundance in the Puente-Chino Hills

Results from track surveys indicate that there is an effect of fragmentation (as represented by the fragmentation factor) on the distribution and abundance of six species throughout the Puente-Chino Hills corridor. Both bobcat and long-tailed weasel had a lower probability of occurring in areas that were more fragmented. These two species were also less abundant in highly fragmented areas. Fragmentation has enhanced the distribution and abundance of mule deer, domestic cat, and domestic dog. Raccoon distribution and abundance was associated with higher levels of wildland. Striped skunk abundance increased with higher levels of fragmentation but was only evident at transects where striped skunk occurred. Opossum occurrence was associated with higher % urban park, although abundance was negatively associated with higher % residential and road density. Coyote and gray fox showed no response to fragmentation

Species Use of Underpasses

Effects of Landscape Variables on Species Usage

Probability of Species Usage

The position of the underpass relative to the surrounding landscape influenced the probability and frequency of species usage. Fragmentation had an effect on the probability of use for four species. Coyote, bobcat, and long-tailed weasel probability of underpass usage was negatively associated with fragmentation, whereas domestic cat probability of underpass usage was positively associated with fragmentation. Bobcat, long-tailed weasel, and domestic cat showed similar associations with fragmentation at track transects. Thus, the probability of underpass usage for many species may simply depend on the probability of that species occurring in the area surrounding the underpass. However, despite long-tailed weasel probability of underpass usage having a negative association with fragmentation, railroad (Mankin and Warner 1997) and roadway (Burke II and Sherburne 1982) rights-of way provide cover for this species.

Coyote probability of underpass use was negatively related to the fragmentation factor and % residential and positively related to corridor width. On the other hand, coyotes showed no association with landscape variables at track transects. A possible explanation as to why landscape variables were significant in determining coyote use of underpasses could be based on movements of coyotes along residential areas. If coyotes utilize the urban-wildland edge for hunting purposes, they may not come in contact with an underpass. Romsos (1998) found that coyotes utilized open habitats juxtaposed to developed areas when making long-distance movements. Gibeau and Heuer (1996) noted that coyotes crossed highways wherever they chose and only used underpasses when it was convenient. The probability of underpass usage may be more likely to occur in more wild areas where the travel routes along the urban edge are absent. In the absence of this interface, hunting may be concentrated along riparian areas, where exposure to underpasses is greater. Additionally, fencing may play a part in determining the probability of coyote underpass use. Generally, underpasses in the more urban areas of the corridor lacked adequate fencing, thus providing an easy opportunity for coyotes to make surface crossings. In wider portions of the corridor, fencing at underpasses was more prevalent. Although not significant, coyotes did tend to use underpasses with no fencing above them less than expected. This could partially contribute to the fact that coyotes were less likely to use underpasses in narrow portions of the corridor.

Aside from the fragmentation factor, other landscape variables played an important role in the probability of species usage. Mule deer probability of underpass usage was negatively associated with corridor width, which was consistent with the probability of occurrence at track transects. Opossum probability of underpass usage was positively associated with % urban park, an association that was consistent with its probability of occurrence. Raccoon probability of underpass usage was negatively associated with corridor width. Although track transects indicated that the probability of occurrence was positively associated with % wild, raccoons moving along riparian areas will eventually come to a roadway. Due to a majority of underpasses being situated along drainages, the probability of a raccoon encountering an underpass is very high, as they almost exclusively use these riparian areas as travel routes. In fact, raccoons used underpasses containing pools of standing water (Foster and Humphrey 1995), a habit that may be attributed to higher amphibian concentrations and other raccoon prey (Land and Lotz 1996; Hewitt et al. 1998).

Gray foxes, which showed no association between probability at track transects and the landscape variables, exhibited a negative relationship between probability of underpass use and corridor width. Gray fox, like coyotes, tend to use both wildland and urban landscapes as part of their home range. But unlike coyotes, gray fox were more likely to use underpasses in narrower portions of the corridor. One factor contributing to this trend could be the temporal and spatial avoidance of coyotes by gray fox. Crooks and Soulé (1999) noted that in habitat fragments that were visited only temporarily by coyotes, gray fox abundance was higher during periods without coyotes than in periods with coyotes. Additionally, they noted that in areas where coyotes were always present, gray fox visited the same scent station on the same night significantly less than expected. This indicates that gray foxes avoid sites where coyotes are most active.

Frequency of Species Usage

When including all underpasses, the fragmentation factor was negatively associated with the frequency of underpass use for bobcats, an association that was consistent with their frequency of occurrence at track transects. Long-tailed weasel and domestic cat were not included in the analysis because of their distribution. Weasels were found in the least fragmented portion of the study area and domestic cats were found in the most fragmented portion of the study area. Although the nature of their distribution did not allow for an analysis, it is likely that the frequency of underpass usage is related to fragmentation (domestic cats positively associated and weasels negatively associated).

In contrast, when analyzing only underpasses that were used by a species, frequency of underpass usage was always positively associated with the fragmentation factor for those species in which a significant correlation was found. When considering all underpasses, bobcat frequency was positively associated with the fragmentation factor. When only considering those underpasses used by a species, the relationship between the fragmentation factor and frequency of underpass use was also positive for coyote, opossum, raccoon, and striped skunk.

Corridor width was an important factor in predicting usage by several species, and the frequency of underpass usage varied depending on whether all of the underpasses were analyzed or whether only those that were used by a species were considered. For example, when including all underpasses, both bobcats and coyotes showed a negative association with the fragmentation factor and/or fragmentation-related variables. Bobcat frequency of underpass use was positively associated with % wild and negatively associated with % residential, road density, and fragmentation. Coyote frequency of underpass use was positively associated with corridor width. However, when only those underpasses that were used by bobcats or coyotes were analyzed, the association with fragmentation-related variables became positive. Bobcat frequency of underpass use was positively associated with road density and fragmentation and negatively associated with corridor width. Coyote frequency of underpass use was positively associated with % urban park, % residential, road density, and fragmentation and negatively associated with % wild. Clearly, there is a difference in the direction of association between frequency of underpass use and the landscape variables. Several possibilities may explain these results.

One problem in analyzing the frequency of usage of underpasses in narrower portions of the corridor is that these areas only contained one or two underpasses, whereas wider portions of the corridor often have more opportunities for animals to use a greater variety of underpasses. Therefore, frequency of underpass usage in narrower portions of the corridor may be higher for bobcats and coyotes due to the funneling effect of few underpasses in that portion of the corridor.

This funneling effect also may explain the positive association between fragmentation and the frequency of underpass usage by other species. If a particular species was more likely to occur in narrower portions of the corridor, then this would increase the chance of exposure to an underpass. Such may be the case for striped skunks. The relative abundance of striped skunk at track transects was negatively associated with corridor width, therefore it is probable that striped skunk were also more frequent at underpasses in narrow sections of the corridor. Opossums and raccoons showed the same positive association between the fragmentation factor and the frequency of underpass use (when only analyzing those underpasses that they used). Although opossum relative abundance at transects was negatively associated with % residential and road density, the probability of occurring at a transect was positively predicted by % urban park (which also predicted the probability of an opossum using an underpass).

Although it seems as if opossum are utilizing both wildland and urban parks adjacent to residential areas, their association with fragmentation relative to frequency of use may be enhanced by the funneling effect created in narrower portions of the corridor. The same holds true for raccoon relative abundance, which was positively associated with % wild. Raccoon probability of using an underpass was negatively predicted by corridor width. Again, the funneling effect may contribute to the increased frequency in underpass usage in narrow sections of the corridor. Therefore, funneling effects are likely occurring for these species, as well as for coyotes and bobcats. Although these species weren't necessarily more abundant in narrow portions of the corridor, the frequency of underpass use increased as the corridor became more constricted.

Effect of Underpass Dimensions on Species Usage

Probability of Species Usage

Only mule deer and gray fox usage at underpasses was affected by underpass dimensions. Mule deer used underpasses that were wider, higher, and more open. Underpass dimensions have been identified as a critical component in successfully allowing for mule deer usage (Reed 1981, Bruinderink and Hazebrook 1996) and it is recommended that the openness at underpasses exceed 0.6 m (Reed et al. 1979). Only one underpass with an openness less than 0.6 m was used by deer in this study: the Colima Road service tunnel (0.425 m). All underpasses in this study that had an openness greater than 0.6 m were used by mule deer and included Culvert 18 on CA

Route 71 (0.607 m) and the CA Route 57 overpass (700.00 m). In Banff National Park, Clevenger (1998) found that underpass openness and height were positively associated with ungulate usage and Foster and Humphrey (1995) found that white-tailed deer in Florida used underpasses as narrow as 12.2 m and as low (in height) as 6.1 m. Mule deer in this study used underpasses as narrow as 4.27 m (Colima Road service tunnel) and as low as 4.57 m (culvert 18 on CA Route 71). Open span bridges offer the optimal setting for mule deer to cross roadways. In a survey of underpass use in urban San Diego, open span bridges were the most consistently used type of underpass used by mule deer, and only one circular and box underpass were ever used (Mock et al. 1992). Reed (1981) noted that mule deer exhibited reluctant behavior at small underpasses, and were less reluctant at larger open span bridges. Disturbances such as construction can also deter deer from using underpasses. Ward (1982) found that mule deer failed to use underpasses for up to three months after a stretch of roadway was fenced off to reduce vehicular collisions with deer. This association was documented on CA Route 71 when, eight months after freeway construction terminated, mule deer began to utilize a newly constructed underpass.

Gray fox probability of underpass use was positively associated with the underpass size factor. This implies that gray fox used underpasses that were shorter in length, wider, higher, and therefore more open. Harrison (1997) recorded a gray fox using a culvert 2 m in height under Interstate Route 40 in New Mexico. Gray fox use of underpasses in this study may have been confounded by the location of large underpasses relative to gray fox distribution. Areas that supported gray foxes tended to have underpasses that were more open. Thus, the relationship between gray fox and openness may simply be due to the distribution of foxes and underpasses along the corridor, and not necessarily the dimension of the underpasses themselves.

Frequency of Species Usage

Although underpass dimensions were not important in determining the probability of usage by many species, they were important in determining the frequency of usage by coyote, gray fox, mule deer, and raccoon. Four species showed an association with multiple underpass dimensions. When including all underpasses in the analysis, coyotes used underpasses more frequently as openness increased. Along CA Route 71, the five underpasses with the greatest openness (0.153 m- 0.607 m) had an average coyote frequency of 0.348, whereas the five underpasses with the least openness (0.008 m- 0.018 m) had an average coyote frequency of 0.018. When analyzing only those underpasses that were used by coyotes, frequency of underpass usage also increased as underpass width and height increased. Coyotes along CA Route 71 never used underpasses less than 1 m in width and height. The average frequency of coyote use at the 16 underpasses along CA Route 71 less than 1.5 m in width in height was 0.025, whereas the 12 underpasses greater than 1.5 m in width and height had an average coyote frequency of 0.249. Gray fox frequency of underpass use increased with the underpass size factor. Therefore, gray fox frequency was associated with underpasses that were shorter in length, wider, higher, and thus, more open. Gray foxes used underpasses ranging in openness from 0.136 m to 700.00 m. Frequency of underpass use was highest at the underpass with the greatest openness (openness = 700.00; frequency = 0.192). Mule deer frequency of underpass usage was positively associated with underpass width, height, and openness.

Three species showed associations with one type of underpass dimension. Bobcat frequency of underpass usage was positively associated with underpass width, but only at those underpasses that were used by bobcats. The average bobcat frequency at the 5 widest underpasses used by bobcats (width > 2.44 m) was 0.206, whereas the average bobcat frequency at the 5 narrowest underpasses used by bobcats (width < 1.07 m) was 0.014. Mock et al. (1992) reported that bobcats used bridges more frequently than pipe and box underpasses. Opossum frequency of underpass usage was positively associated with length, but this association was only at those underpasses that were used by opossums. The average opossum frequency at the 5 longest underpasses used by opossums (length > 76.0 m) was 0.151, whereas the average opossum frequency at the 5 shortest underpasses used by opossums (length < 37.0 m) was 0.064. When all underpasses were analyzed, raccoon frequency increased at underpasses that were higher. The average raccoon frequency at the 9 highest underpasses (height > 3.05 m) was 0.49, whereas the average raccoon frequency at the 19 lowest underpasses (height < 1.07 m) was 0.002. Additionally, when analyzing only those underpasses that were used by raccoons, raccoon frequency of underpass usage was positively associated with underpass width.

Effects of Cover Surrounding Underpass Entrances on Species Usage

The type and amount of cover surrounding the underpass entrance was important for several species. When analyzing all underpasses, bobcat and gray fox probability of underpass usage was positively associated with % natural cover. The frequency of underpass usage by these two species, as well as opossum, was also positively associated with % natural cover. The eight underpasses surrounded by greater than 75% natural cover had an average bobcat frequency of 0.124, whereas the nine underpasses surrounded by less than 10% natural cover had an average bobcat frequency of 0.007. At these same underpasses, gray fox frequency was 0.440 at underpasses surrounded by greater than 75% natural cover, compared to a frequency of 0.000 at underpasses surrounded by less than 10% natural cover. The average opossum frequency at the underpasses surrounded by greater than 75% natural cover was 0.115, compared to a frequency of 0.004 at underpasses surrounded by less than 10% natural cover. In Spain, Rodriguez et al. (1996) found that carnivore crossing rates along a railway were significantly lower at underpasses without cover near their entrances. Bruinderink and Hazebrook (1996) recommend that the area surrounding underpass entrances and exits should be given the status of a refuge, and be managed exclusively for wildlife. In a study of large mammal movements in Banff National Park, carnivore usage at underpasses has been negatively associated with human activity (Clevenger 1998). Human presence not only disturbs some species of wildlife, it also may reduce the amount of cover surrounding the underpass entrance.

Effects of Fencing and Roadway Dividers on Species Usage

Fencing along freeways can reduce the probability of wildlife collisions along roadways (Ward 1982; Feldhamer et al. 1986; Boarman and Sazaki 1996; Roof and Wooding 1996). In this study, along CA Route 71, fencing type was correlated with roadway divider type. Generally, those underpasses that contained no fencing did not have a barrier on the roadway above. Similarly, those underpasses with an 8-ft high chain link fence were under sections of roadway divided by a concrete barrier. Coyotes showed a response to the type of roadway divider. When the two types of dividers (guard rail and concrete barrier) were combined, coyotes used underpasses with no divider on the roadway less than expected and underpasses with a divider on the roadway more than expected. Given the correlations between barrier type and fence type, the response to fencing type along the roadway is not surprising.

Fencing was also important for coyotes, as they showed a response to the type of fencing above the underpass. However, there was no significant association with a particular fence type after pooling together barbed-wire fencing and 8-ft high chain link fencing and comparing use against underpasses with no fencing. Fencing has been recommended as a tool in guiding animals to underpasses (Ward 1982; Foster and Humphrey 1992; Mock et al. 1992; Bruinderink and Hazebroek 1996). In Florida, coyote, bobcat, white-tailed deer, gray fox, and raccoon walked along roadway fencing rather than attempting to cross through it or under it (Roof and Wooding 1996).

Summary of Species Responses to Underpasses

The probability of underpass use was almost entirely dependent on the landscape variables analyzed, whereas the frequency of underpass use depended mainly on the dimensions of the underpass. Of the nine species having an association between the probability of underpass usage and any of the variables analyzed, only 2 species (mule deer and gray fox) showed an association with some type of underpass dimension (length, width, height, and/or openness). However, all nine species were associated with some type of landscape variable. Of the eight species having an association between the frequency of underpass usage and any of the variables analyzed, seven species showed an association with some type of underpass dimension. However, landscape variables were still important in determining how frequently the underpass was used by a species, as seven of the eight species showed an association with some type of landscape variable. Therefore, in order to maximize the probability of usage, underpasses should be placed with respect to landscape characteristics. Upon placement of underpasses, the dimensions are critical in increasing the frequency of usage by a particular species. Thus, an underpass with adequate dimensions may not fulfill its purpose if it is not situated in an optimal setting.

On a landscape level, when including all underpasses, bobcat and long-tailed weasel probability and frequency of underpass usage were negatively associated with fragmentation. Coyote probability of underpass usage also was negatively associated with fragmentation, and frequency of underpass usage was negatively associated with corridor width. This indicates that the successful movement of coyotes and bobcats (acknowledging that weasels were only found in Section 1 and probably lack the dispersal capabilities of the larger predators) depends on the positioning of underpasses relative to the landscape. Successful movement also depends on the dimension of the underpass. Of the underpasses visited by bobcats or coyotes, bobcat frequency of use increased at wider underpasses and coyote frequency of use increased at wider and higher underpasses.

Mule deer probability and frequency of underpass usage was mostly dependent on dimension variables. Therefore, corridor width, although a significant predictor of the probability of mule deer usage of underpasses, is not as important a factor, because mule deer were more abundant in narrower portions of the corridor. Mule deer frequency of underpass use was not associated with corridor width. However, Rodriguez et al. (1996) found that ungulate avoidance of underpasses was probably due to a combination of unsuitable dimensions and placement.

Gray fox probability of underpass usage was almost entirely dependent on underpass dimension. Corridor width was the only landscape variable associated with the probability and frequency of gray fox underpass usage (frequency of use increased in narrow portions of the corridor). Indeed, fox distribution was not affected by fragmentation, indicating that gray fox occur in both open space and residential areas.

Opossum, raccoon, and striped skunk showed varying responses to underpass dimension and location relative to the landscape. The probability of underpass usage was positively associated with some type of landscape variable. All three species used underpasses more frequently in more fragmented areas, and some type of underpass dimension was associated with opossum and raccoon frequency of underpass use. This indicates that these species are less sensitive to variation in underpass dimensions when compared to larger species (mule deer, coyote, bobcat, and gray fox).

Domestic cat probability and frequency of underpass usage (at those underpasses that were used by cats) was positively associated with some type of fragmentation variable. This is largely due to their distribution throughout the Puente-Chino Hills corridor. In areas with increasing fragmentation, an increase in the frequency of underpass use (as documented in the Puente-Chino Hills corridor) may affect the success of smaller prey species that are typically preyed upon by domestic cats. This introduces a potential disadvantage to corridors, as exotic species may exert pressures on native species attempting to utilize a narrow strip of open space.

RECOMMENDATIONS

Although restoring critical areas within the corridor may seem daunting, mitigation measures can ensure that current and future impacts to the corridor do not prevent continued movement of species between patches.

Areas of Concern in the Puente-Chino Hills

Habitat fragmentation from a series of roadways in the Puente-Chino Hills has resulted in a chain of various sized patches of open space (Figures 2, 3). Along the entire corridor, three constrictions from encroaching urban development are evident: 1) Harbor Boulevard, 2) the Skyline Trail between Powder Canyon Open Space and Hacienda Boulevard, and 3) the stretch of open space between Hacienda Boulevard and Colima Road. These constrictions are particularly vulnerable to habitat degradation as a result of a high level of human activity. While the negative impact of human activity on wildlife most likely will not be as severe in larger areas of habitat within the corridor, it is a serious concern in places where habitat is minimal.

Harbor Boulevard

The first constriction, as one moves east to west, is the area surrounding Harbor Boulevard (Figure 15). The encroachment of development from the north and south has created a narrow stretch of open space on both sides of the roadway. Combined with lack of adequate cover and high traffic volume, movement across this road is dangerous.

The location of the Vantage Pointe Community has split the remaining open space into two choke points along Harbor Boulevard. The first choke point is at the north end of Harbor Boulevard in the vicinity of the equestrian tunnel. Only raccoon and skunk were detected moving through this tunnel. This tunnel also receives much human activity. Coyotes are attempting to surface cross Harbor Boulevard at this location, as several road kills were found over the course of this study.

While it is clear that the northern linkage across Harbor Boulevard (specifically the equestrian tunnel) is functioning for raccoons and skunks, the tunnel was not used by most species. Although coyotes, foxes, and opossums were detected in the vicinity of the northern linkage, these three species were never detected using the equestrian tunnel. Moreover, deer and bobcat were never detected in the vicinity of the northern linkage. More species were detected along Harbor Boulevard in the vicinity of the southern choke point. This choke point, which constitutes the DPW property on the east and west sides of Harbor Boulevard, contained evidence of bobcat, coyote, deer, fox, opossum, skunk, and raccoon. Coyote and deer were recorded making surface crossings over Harbor Boulevard at this location, as indicated by tracks leaving scent stations established along the roadway. Although no road-killed deer were found along this stretch of road, there were many reports of wildlife-vehicle mortality involving coyotes.

Skyline Trail

The second area of concern is along the Skyline Trail between Powder Canyon Open Space and Hacienda Boulevard (Figure 16). Human activity throughout this area is extremely high and index values for dogs were highest along this stretch. In addition, the open space within this stretch is characterized by a narrow east-west running ridgeline bordered by canyons that drop steeply to the north and south. Although the ridgeline is almost entirely comprised of the Skyline Trail, the side canyons do support some habitat.

This stretch is most critical to bobcats, since this section received the lowest average bobcat index within the entire corridor. Interestingly, sections within the corridor displaying low bobcat track indices contained high levels of dog activity (Figure 14).

Hacienda Boulevard to Colima Road

The third critical area is the stretch of open space between Hacienda Boulevard and Colima Road (Figure 17). There are two areas of concentration of movement across Hacienda Boulevard to Colima Road, north and south. The northern movement route is along the Skyline Trail between the Hacienda Boulevard equestrian tunnel and the Colima Road equestrian tunnel. Human disturbance and habitat degradation on this segment of trail are the major threats to animal movement and may explain why no bobcat or fox activity was recorded along this stretch.

The southern movement route extends along Skyline Drive and west into San Miguel Canyon. The eastern portion of this movement route is characterized by low-density housing, but it is not a barrier to movement. Bobcat activity was documented on the east side of Hacienda Boulevard, just north of the Skyline Drive and Hacienda Boulevard intersection. Bobcat activity was also documented on the west side of this intersection, indicating that movement is occurring at the crest of the hill where Skyline Drive and Hacienda Boulevard meet (Figure 17). Therefore, when animals are travelling east to west along the corridor through this section, they are likely moving west along

Skyline Drive, descending into San Miguel canyon in the southwest portion, and finally moving through the Service Tunnel under Colima Road.

Section 1: CA Route 91 to Carbon Canyon Road (CA Route 142)

The eastern edge of the Puente-Chino Hills corridor is the most critical, and probably the only, link that will ensure exchange of individuals between the Santa Ana Mountains and eastern Chino Hills. Due to extensive urbanization surrounding the hills, the only option for dispersing individuals to leave the Puente-Chino Hills corridor is through the Coal Canyon Biological Corridor. In fact, telemetry data have validated juvenile coyote (Lisa Lyren, pers. comm.) and mountain lion dispersal (Beier 1993) from the Chino Hills across CA Route 91.

While additional linkages between the Puente-Chino Hills and larger natural areas may exist, such as the San Gabriel River to the San Gabriel Mountains, they involve extensive distances of travel. The San Jose Hills, a patch of open space in close proximity to the Puente-Chino Hills, is almost completely isolated by urban development (Figure 1). However, a telemetry study of coyotes in this area in the late 1980's documented a coyote moving from the San Jose Hills south to the Chino Hills (Glenn Stewart, pers. comm.) and a coyote from the CA Route 71 telemetry study traveled from the Chino Hills to the Cal Poly campus (Lisa Lyren, pers. comm.). Movement from the San Jose Hills to the San Gabriel Mountains is even less likely.

The Prado Flood Control Basin is separated from the Chino Hills by CA Route 71 (Figure 18). Despite carnivore movement across this highway between the Chino Hills and Prado Basin, movement beyond Prado basin is unlikely, because the remainder of Prado Basin is surrounded by urbanization and agriculture. This does not entirely mean that these areas will not experience movement of individuals into or out of a locale, but rather that species attempting to move will most likely be those that can travel long distances and are compatible to human presence.

As a result, the Coal Canyon Biological Corridor represents the best available, and perhaps the only, link between the Puente-Chino Hills and larger areas of habitat (Figure 19). With the exception of CA Route 91 through Santa Ana Canyon, the Chino Hills and Santa Ana Mountains are almost physically in contact. Movement between these patches is occurring, but it is primarily restricted to the Coal Canyon culvert (91 East), Coal Canyon Road underpass, and several culverts and underpasses to the east of CA Route 71 that were not monitored during the course of this study. Obviously, a major threat to this connection is development. Currently, negotiations are underway to acquire and preserve properties on both the north and south sides of CA Route 91, thus providing a secure connection between the Chino Hills and Santa Ana Mountains.

Once the Coal Canyon Corridor is secured, several measures can be undertaken to enhance the connection. First, eliminating traffic at the Coal Canyon Road off-ramps and underpass would reduce noise, vehicle activity, and the probability of wildlife-vehicle incidents. Second, the current fencing design presents a barrier for wildlife attempting to use the underpass. While certain species are utilizing the culvert (91 East) adjacent to the Coal Canyon Road underpass, other species such as deer may be deterred due to its low height (2.44 m) and long length (200 m). Rerouting the fencing so that animals can travel through the underpass while being prevented from accessing the freeway would allow for a wider range of species to cross under CA Route 91. Obviously, facilitating the movement of animals through the underpass (under the bridge) must involve closing the exit. Finally, natural cover should be provided through the bridged underpass so that any animal attempting to utilize it does not have to cross a large area devoid of vegetation. Furthermore, native cover may attract animals to the entrance, thus increasing the likelihood that they will find the entrance and attempt a crossing.

Several modifications to the existing conditions on CA Route 71 also are necessary to reduce wildlife-vehicle collisions. Perhaps the most significant impact on wildlife occurs on that portion of freeway immediately north of CA Route 91. This 500 m stretch of freeway lacks fencing and center dividers. As a result, at least 16 coyotes have been hit by vehicles from June 1997 to January 2000 (Lisa Lyren, pers. comm.). Because underpasses were used more than expected when there was 8-ft high chain link fencing above them, all of the underpasses should contain fencing between their entrance and the freeway.

Generally, Section 1 contains the majority of protected open space within the entire Puente-Chino Hills, largely due to Chino Hills State Park. All of the major canyons have evidence of bobcat, coyote, and fox. Mountain lion sighting and sign also have been recorded over the past two years. These signs were documented by myself during preliminary investigations and by Chino Hills State Park rangers. Clearly, this area, combined with Section 2, represents the most crucial block of core habitat within the Puente-Chino Hills corridor.

Section 2: Carbon Canyon Road (CA Route 142) to CA Route 57

Development threats along Carbon Canyon Road are encroaching on the remaining open space between the cities of Brea and Chino Hills (Figure 20). The increasing urbanization throughout this area has resulted in increasing traffic on Carbon Canyon Road. Although this roadway is only two lanes, wildlife mortality is still occurring. Road kill may be partially due to the lack of underpasses along this stretch of road, thus forcing animals to make potentially dangerous surface crossings.

Six underpasses were monitored between Carbon Canyon Regional Park and Sleepy Hollow. Two of these culverts (Monterey East and West, connecting Carbon Canyon Regional Park and the Olinda Heights development) have been filled by dirt due to nearby development. Thus, any animals attempting to cross this stretch of Carbon Canyon Road will be forced to make a surface crossing. However, given the future plans for a residential area at this site, animals will most likely cross to the east of this location, at the western entrance to Chino Hills State Park. Ultimately, as traffic along this road increases, more fencing will be needed to direct animals to new culverts, in order to reduce road kill.

Further east, between Chino Hills State Park and Olinda Village, the only option to cross the road is a surface crossing. Indeed, track stations have recorded coyotes making such attempts. Carbon Canyon Road is not the barrier that CA Route 91 is: it is two lanes wide, the traffic volume is lower, and speeds are reduced. However, given increasing traffic volume, any upgrades to this road will require adequate crossing structures.

It is difficult to determine what exact routes animals will take during travels from one side of Carbon Canyon Road to the other. As track stations along Carbon Canyon Road demonstrated, many of the side canyons perpendicular to the road are being used by a variety of species. However, two particular areas along this road are critical in maintaining connections between the major drainages to the south and east (Telegraph and Soquel Canyons) and the north and west (Sonome and Tonner Canyons). These locations are essential primarily due to their connectivity value for bobcats. The first connection is through the western end of Chino Hills State Park, along the citrus grove. Citrus Grove East culvert had a high degree of bobcat activity and connects Telegraph Canyon on the south with newly acquired State Park lands to the north.

The second connection between major drainages to the southeast and northwest of Carbon Canyon Road is between Olinda Village and Sleepy Hollow (Figure 20). The County Line culvert at Sleepy Hollow also received bobcat activity and is critical in maintaining connections between Soquel Canyon to the south and Lions Canyon to the north. Although there is no direct link between Soquel Canyon and Sonome Canyon, many of the side canyons extending out of Carbon Canyon provide the opportunity for movement between Soquel and Sonome Canyons. Furthermore, because the Sonome Canyon region has the highest bobcat track indices throughout the entire corridor, it is essential that connections to this locality are preserved so that dispersal of bobcats into and out of Sonome Canyon can continue. Additionally, the presence of mountain lion scat in Carbon Canyon emphasizes the fact that, if development continues along this road, valuable connections may be severed.

Although bobcat activity was not recorded on the Carbon Canyon Road track stations between Olinda Village and Chino Hills State Park, coyotes were detected. Since there are no culverts along this stretch of road, all crossing attempts are made at-grade. Again, increasing traffic volume may have a significant impact on wildlife mortality along this stretch of road.

Further west, the Puente-Chino Hills corridor is bisected by CA Route 57 (Figure 21). The open span bridge over Tonner Canyon provides unrestricted access to adjacent open space. This is the only underpass under CA Route 57 that is being used by wildlife, and it is, therefore, a choke point. However, because Tonner Canyon is a large, spanning bridge, movement currently is not restricted as much as other choke points along the corridor.

Although bobcat activity was concentrated along Tonner Canyon Road, future plans for development will probably reduce the likelihood that bobcats will continue to use this route. Consideration should be given to revegetating the riparian area along the streambed, as oil company activities have severely degraded this portion of the canyon.

Section 3: CA Route 57 to Harbor Boulevard

The majority of this section is located on lands owned by Shell Oil Company and was not surveyed. Given the degree of open space and lack of development in this section, it is likely that the Shell Oil property supports species commonly found throughout Tonner Canyon. Movement through this area is unrestricted until Harbor Boulevard is reached. This 4-lane road receives a high volume of traffic, and when combined with the encroachment of development from both north and south, represents the next significant barrier to wildlife movement from east to west.

Although raccoons and skunks used the equestrian tunnel, its position along Harbor Boulevard does not allow for a greater number of species to utilize it (Figure 15). Furthermore, the lack of fencing to direct these animals through the underpass likely contributes to the road kill (e.g. coyotes). This does not mean that fencing should be placed along the entire stretch of Harbor Boulevard. Rather, fencing should be installed along Harbor Boulevard adjacent to the equestrian tunnel to funnel animals through it.

Ideally, the southern portion of the Harbor Boulevard choke point also should contain some type of underpass, preferably large enough to facilitate deer movement. Fencing along this stretch of road should only be done in the event that an underpass is constructed. Although fencing without an underpass would more than likely reduce, if not eliminate, road kill along this stretch of road, it would create a barrier in itself by blocking all movement across Harbor Boulevard. If there was fencing without an underpass on the southern portion, then the sole crossing point at Harbor Boulevard would be the equestrian tunnel to the north, which receives limited carnivore usage. In addition, movement between the southern portion and the northern portion is unlikely due to the intervening urban development.

Aside from adding fencing along the northern section of Harbor Boulevard, natural cover should replace any form of landscaped vegetation surrounding the equestrian tunnel. Throughout the corridor, bobcats more frequently used underpasses with lower levels of landscaping (relative to natural vegetation) surrounding the entrance.

Section 4: Harbor Boulevard to Hacienda Boulevard

The area between Harbor Boulevard and Powder Canyon Open Space is mostly comprised of low-density housing (Figure 15). Currently, the presence of houses in this area does not seem to be a significant barrier to movement. The Edison easement at the western boundary of the Vantage Pointe Community received activity by bobcats, coyotes, foxes, and skunks, and represents the eastern extent of carnivore movement into Powder Canyon. The small canyons to the north and west of this transect (and the Edison easement) offer the most likely movement routes into Powder Canyon.

Since Fullerton Road is a small, two-lane road that receives limited traffic, it is unlikely that this is a major barrier to carnivore movement. The winding nature of this road between Harbor Boulevard and East Road prevents vehicles from travelling at excessive speeds. Coyote activity was documented along Fullerton Road at two individual scent stations. While the threat of increased traffic volume is not imminent, future monitoring of road kills should be conducted.

Powder Canyon Open Space, in conjunction with Schabarum Regional Park to the north, provides a relatively large area of habitat for resident wildlife populations (Figure 16). With the exception of raccoons and weasels, all of the species detected throughout the Puente-Chino Hills were found in Powder Canyon Open Space. However, bobcats exhibited lower indices relative to other areas of the corridor.

Further west, as the corridor becomes more constricted, human activity increases. The side canyons extending north and south of the Skyline Trail represent the best available habitat at the western end of this section. It is critical that these canyons be protected in order to alleviate the impacts of human activity along the Skyline Trail.

Section 5: Hacienda Boulevard to Colima Road

Although Hacienda Boulevard receives a relatively high volume of traffic, there is no serious threat of wildlife-vehicle collisions. This is largely due to the fact that Hacienda Boulevard is steep and somewhat winding as it crosses the corridor between the Hacienda Boulevard equestrian tunnel and Skyline Drive. As defined earlier, there are two primary routes of travel within this section: a north route and a south route (Figure 17).

Animals attempting to cross Hacienda Boulevard to gain access to the northern route are either travelling through the Hacienda Boulevard equestrian tunnel or across Hacienda Boulevard (make a surface crossing). Since the only species detected using the equestrian tunnel were raccoons and domestic cats, it is likely that other animals also are making surface crossings in this area. Indeed, scent stations on each side of Hacienda Boulevard experienced high visitation by species, especially coyotes, not using the tunnel. The design of this underpass is similar to the equestrian tunnel under Harbor Boulevard in that it lacks adequate fencing to direct animals to the tunnel. Fencing should be placed on both sides of Hacienda Boulevard in the vicinity of the equestrian tunnel, to reduce the possibility of future road kill. In addition, the western entrance to the tunnel lacks adequate levels of natural cover. Revegetation of the area surrounding this entrance to the underpass, in combination with proper fencing design, may increase wildlife usage of this underpass.

The second area that is targeted as a major crossing point across Hacienda Boulevard is at the intersection of Skyline Drive and Hacienda Boulevard. This area is especially critical because it was the only sampling location along this stretch of Hacienda Boulevard where bobcat activity was recorded. If an underpass was installed under Hacienda Boulevard north of Skyline Drive, it might be used by wildlife. However, fencing to direct animals to the underpass would be difficult. For example, Skyline Drive is a small, graded road that animals will travel down to cross Hacienda Boulevard at the intersection. To direct animals through a tunnel under Hacienda Boulevard, a fence would need to be constructed across Skyline Drive to prevent animals from simply walking down the road. This, obviously, is not feasible. Even if wing fencing was constructed just directly above an underpass at Hacienda Boulevard, a surface crossing would still be possible, and the design would mirror current conditions at the equestrian tunnels under Harbor Boulevard, Hacienda Boulevard, and Colima Road. In other words, it is not likely that the conditions at this southern crossing point could be improved.

Between these two major crossing points there are many side canyons extending north and south from Hacienda Boulevard. Sampling between the north and south routes through Section 5 occurred along the stretch of Skyline Trail paralleling Hacienda Boulevard. Coyotes were detected traveling along this stretch of trail, although visitation rates to scent stations were low. Therefore, surface crossings over Hacienda Boulevard along the stretch between the equestrian tunnel and Skyline Drive are limited, and probably not as significant as crossings to the north and south. The best strategy to avoid turning Hacienda Boulevard into a critical choke point is to continue purchasing lands along the roadway, so that development does not block any wildlife movement across this road.

Once animals have crossed Hacienda Boulevard, there appear to be two primary routes of travel from east to west: through the northern half of the section or through the southern portion. Scent stations throughout the northern half of this section along Skyline Trail were never visited by bobcat or fox. Indeed, this area is generally lacking in adequate cover and receives a great deal of human activity. This does not mean that movement through this portion of Section 5 is not occurring, although even coyote indices were fairly low. Rather, the northern half of this section represents a buffer to habitat south of this area.

Habitat protection in the southern portion of this section, although mixed with low-density housing toward Hacienda Boulevard, is critical to maintaining resident populations of wildlife. For example, the least disturbed portion of this section occurs in San Miguel Canyon. Of the transects throughout Section 5, the transect through this canyon recorded the highest track and scat indices for bobcats, coyotes, and foxes and the highest track indices for raccoons and skunk. Incidentally, dog indices were lowest along this transect. Therefore, the purchasing of lands for further habitat protection would help to secure the remaining areas of open space within this section.

Section 6: Colima Road to Turnbull Canyon Road

Sampling within this section was confined to the eastern half due to restrictions on access to Rose Hills Memorial Park in the western half (Figure 22). The existing open space throughout Rose Hills Memorial Park is characteristic of the habitat within the sampled portion of this section (City of Whittier property). Therefore, it is assumed that the species detected on transects established throughout the eastern half of this section would also occur in the western portion.

There are two underpasses located under Colima Road (Figure 22). The northern underpass is the Colima Road equestrian tunnel. This tunnel was used by opossums, raccoons, skunks, dogs, and cats. The design is similar to those equestrian tunnels along Hacienda Boulevard and Harbor Boulevard in that there is no fencing to prevent wildlife from making an at-grade crossing of Colima Road. Scent stations on each side of the road recorded coyote visits, indicating that there is activity across the road. Coyote movement across Colima Road was further substantiated by numerous road kills at this location over the course of this study. By establishing fencing along both sides of the road, animals would be prevented from attempting surface crossings. The eastern entrance of this tunnel is surrounded by adequate cover, but cover on the western side is lacking. Although this equestrian tunnel is being utilized by more species (5) than the Harbor and Hacienda equestrian tunnels (2 species each), two of the five species detected under the Colima Road tunnel are domestic animals (dogs and cats). Additionally, no bobcats, coyotes, deer, or foxes were detected using this tunnel. The proximity of this underpass to residential development is more than likely influencing species usage.

The southern underpass is a service tunnel and was used by bobcats, deer, foxes, opossums, and skunks. The lack of domestic species (cats and dogs) at this underpass is due to the lack of influence from residential development. When compared to the equestrian tunnel to the north, the degree of wildland surrounding the service tunnel underpass was inversely similar to the degree of residential area surrounding the equestrian tunnel. Therefore, this provides a means of comparing species usage of underpasses in two different settings (residential and wildland), but along the same stretch of road. Such a scenario is not available on Hacienda Boulevard and Harbor Boulevard.

The eastern portion of Section 6 contains the highest bobcat indices west of Sonome Canyon and the highest levels of deer activity in the entire Puente-Chino Hills corridor. Combined with the fact that evidence of coyote, fox, opossum, raccoon, and skunk was recorded on at least one transect, the wildlands in this section represent a core area of habitat within the Puente-Chino Hills. Currently, Section 6 is large enough to still have areas that receive relatively little impact from anthropogenic influences. These areas, including the City of Whittier property and wildland spaces throughout Rose Hills Memorial Park, restrict human activity and therefore are more likely to contain a higher abundance of mammals.

Recent plans have been made to incorporate the City of Whittier property into a multi-use recreation area. Not only would human activity here interfere with current relatively undisturbed conditions throughout this property, it would disrupt wildlife movement through the service tunnel underpass as animals attempt to cross underneath Colima Road. Since this underpass is the only link between habitat to the east (San

Miguel Canyon) and habitat to the west (Arroyo Pescadero Canyon), human disturbance should be kept to a minimum. It is strongly recommended that all efforts to allow human activity to occur throughout this area be stopped.

Section 7: Turnbull Canyon Road to Workman Mill Road

Due to the excessive winding of Turnbull Canyon Road, it is not a significant barrier to wildlife movement (Figure 23). No road kills were detected along Turnbull Canyon Road during the course of this study, although coyote and deer road kills have been documented (Swift et al. 1993). Species detected along this road included bobcats, coyotes, foxes, opossums, raccoons, and dogs. Generally, the habitat surrounding the road consists of non-native grassland and contains little cover. However, several of the side canyons that cut across Turnbull Canyon Road provide some sort of vegetative cover. These areas are the most likely locations for animals attempting to cross Turnbull Canyon Road.

Further west, sampling was restricted to the Skyline Trail, due to access restrictions from Rose Hills Memorial Park (Figure 24). This stretch of trail is fenced in for some portions and travels through the Los Angeles County Landfill, thus not truly representing the array of habitat found throughout this section. Bobcat sign was detected in Sycamore Canyon during an initial inspection midway through the study. Although Sycamore Canyon was not surveyed with baited scent stations because it was purchased near the end of field surveys, several visits were made to observe evidence of mammals, particularly bobcats. In addition to bobcat sign, there was evidence of coyote, deer, and fox. In November 1999, I also detected a possible mountain lion scat. Conclusive evidence was difficult due to the age of the sample, but unconfirmed sightings are common in this section. Clearly, this area represents important habitat for resident populations of wildlife, and a strong effort should be made to purchase lands linking Sycamore Canyon with larger areas of open space to the east.

A major barrier to wildlife movement is the presence of fencing between Rose Hills Memorial Park and the Los Angeles County Landfill. This area is significant because it connects Sycamore Canyon with many of the smaller canyons extending north and east of the Skyline Trail. The portion of the Skyline Trail that travels between these fences received low visitation rates to scent stations. Breaks in the fence should be installed so as to limit public access, but allow for wildlife movement.

The open space contained within the western Puente Hills ends abruptly at Workman Mill Road. West of this roadway, the landscape is dominated by dense urbanization, representing a significant barrier to any wildlife movement. Although movement beyond Workman Mill Road and Interstate Route 605 is likely for some species detected in this study, particularly coyote, opossum, and raccoon, the extent of their travel into the urban matrix is likely not sufficient to allow them to reach other large blocks of habitat to the north.

CONCLUSIONS

The usefulness of corridors has been supported by relatively little empirical evidence. When analyzing the responses of populations to corridors, it is difficult to test what specific factors, such as corridor width, patch size, habitat quality, and edge effects, species may associate with or to what degree these factors may enhance or restrain a species distribution. While this study did not directly evaluate the response of individuals to fragmentation, it does offer insight as to how local populations are distributed throughout a fragmented system, particularly along a gradient of fragmentation as exhibited by the Puente-Chino Hills corridor.

This study demonstrated the effect fragmentation has on the distribution and relative abundance of carnivores. From these results, extrapolations can be made to speculate how species will respond to increasing development pressures in the Puente-Chino Hills, as well as in other areas experiencing similar development pressures. The first species to be affected by increasing fragmentation in the Puente-Chino Hills will be bobcats and long-tailed weasels. Fragmentation had a negative impact on the distribution and relative abundance of both species, and also affected the probability and frequency of underpass use. Bobcats were detected in the narrowest portions of the corridor, however their probability and frequency of occurrence were low. Increasing development, especially in the narrowest portions of the corridor, may lead to an isolation of the bobcat population at the western end of the Puente-Chino Hills. Therefore, it is critical that corridor width be maximized to increase the probability of bobcat usage. Additionally, large underpasses need to be located away from residential areas in order to increase the probability and frequency of bobcat use.

The next species to be affected by increasing fragmentation will be the coyote. Although, fragmentation did not have a significant effect on the distribution and relative abundance of coyotes, it was negatively associated with the probability of coyote use of

Although many of the landscape variables in this study were associated with the distribution and relative abundance of species across the corridor, they do not encompass certain corridor attributes that occur at a finer scale. Rather, they provide an assessment of the quality of a corridor based on the degree of urbanization surrounding areas of natural habitat. Therefore, there may be other important factors that are selected for when utilizing or avoiding a corridor, and more research needs to address specific variables that are critical in optimizing corridor use for a species.

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Table 1. Spearman rank correlations between landscape variables measured for track transect data (n = 40).

	% Wild	% Residential	% Urban Park	Corridor Width	Road Density
% Wild	1.00				
% Residential	-0.83***	1.00			
% Urban Park	0.55***	-0.27	1.00		
Corridor Width	0.66***	-0.57***	-0.27	1.00	
Road Density	-0.86***	0.86***	-0.35*	-0.67***	1.00

* $p < 0.05$
*** $p < 0.001$

Table 2. Spearman rank correlations between landscape variables measured for underpass data (n = 43).

	% Wild	% Residential	% Urban Park	Corridor Width	Road Density
% Wild	1.00				
% Residential	-0.93***	1.00			
% Urban Park	-0.26	-0.26	1.00		
Corridor Width	0.51***	-0.45**	-0.09	1.00	
Road Density	-0.79***	0.86***	0.29	-0.47**	1.00

** $p < 0.01$
*** $p < 0.001$

Table 3. Spearman rank correlations between dimension variables measured for underpass data (n = 43).

	Length	Width	Height	Openness
Length	1.00			
Width	-0.13	1.00		
Height	-0.04	0.96***	1.00	
Openness	-0.58***	0.82***	0.76***	1.00

*** $p < 0.001$

Table 4. Significant landscape variables associated with the probability of a species' occurrence at a track transect (n = 40) as determined by logistic regression analysis.

	x^2	p	Direction	#*
Bobcat:				19
% Wild	5.67	0.01	+	
Corridor Width	5.29	0.02	+	
Road Density	3.95	0.04	-	
Fragmentation	5.51	0.01	-	
Long-tailed Weasel:				2
% Wild	4.91	0.02	+	
% Residential	9.15	0.002	-	
Road Density	7.89	0.004	-	
Fragmentation	5.74	0.01	-	
Opossum:				22
% Urban Park	4.95	0.02	+	
Raccoon:				12
% Wild	4.17	0.04	+	
Mule Deer:				15
% Residential	6.27	0.01	+	
Corridor Width	7.94	0.004	-	
Road Density	4.31	0.03	+	
Fragmentation	6.18	0.01	+	
Domestic Dog:				32
% Wild	4.94	0.02	-	
% Urban Park	5.71	0.001	+	
Corridor Width	4.54	0.03	-	
Fragmentation	4.58	0.03	+	
Domestic Cat:				2
% Wild	4.65	0.03	-	
% Residential	5.67	0.01	+	
Corridor Width	4.39	0.03	-	
Road Density	15.57	< 0.001	+	
Fragmentation	7.72	0.005	+	

* = the number of transects where the species was detected

Table 5. Spearman rank correlations between landscape variables and relative abundance of a species at a track transect.

	Visited Transects			All Transects (n = 40)	
	r_s	p	n*	r_s	p
Bobcat:			19		
% Wild	0.51	0.02		0.45	0.003
% Residential	-0.49	0.03		-0.35	0.02
Corridor Width				0.35	0.02
Road Density	-0.54	0.01		-0.40	0.01
Fragmentation				-0.41	0.008
Long-tailed Weasel:*			2		
% Wild				0.31	0.05
% Residential				-0.35	0.02
Road Density				-0.34	0.03
Fragmentation				-0.31	0.05
Opossum:			22		
% Residential	-0.48	0.02			
Road Density	-0.41	0.05			
Raccoon:			12		
% Wild				0.31	0.05
Mule Deer:			15		
% Residential				0.34	0.03
Corridor Width				-0.37	0.01
Fragmentation				0.34	0.03
Striped Skunk:			28		
% Wild	-0.42	0.02			
% Urban Park	0.50	0.01			
Corridor Width	-0.54	0.00		-0.43	0.005
Road Density	0.42	0.02			
Fragmentation	0.38	0.04			
Domestic Dog:			32		
% Wild				-0.50	< 0.001
% Residential				0.44	0.004
Corridor Width	-0.63	< 0.001		-0.62	< 0.001
Road Density	0.36	0.04		0.38	0.01
Fragmentation	0.46	0.01		0.51	< 0.001
Domestic Cat:*			2		
% Wild				-0.31	0.05
% Residential				0.33	0.03
Corridor Width				-0.32	0.04
Road Density				0.38	0.01
Fragmentation				0.34	0.03

* = the number of transects where the species was detected

** = species detected at 2 transects, visited transect analysis not run

Table 6. Significant landscape variables associated with the probability of a species using an underpass (n = 43) as determined by logistic regression analysis.

	x^2	p	Direction	#*
Bobcat:				20
% Wild	14.61	< 0.001	+	
% Residential	13.92	< 0.001	-	
Road Density	12.43	< 0.001	-	
Fragmentation	11.33	< 0.001	-	
Long-tailed Weasel:				6
% Wild	5.66	0.01	+	
% Residential	5.73	0.02	-	
Corridor Width	5.66	0.01	+	
Road Density	6.66	0.009	-	
Fragmentation	8.97	0.002	-	
Coyote:				25
% Residential	5.16	0.02	-	
Corridor Width	3.76	0.05	+	
Fragmentation	4.93	0.02	-	
Gray Fox:				4
Corridor Width	7.37	0.006	-	
Opossum:				21
% Urban Park	3.61	0.05	+	
Raccoon:				14
Corridor Width	3.98	0.04	-	
Mule Deer:				3
Corridor Width	3.93	0.04	-	
Striped Skunk:				32
% Urban Park	4.50	0.03	+	
Domestic Cat:				5
% Wild	4.75	0.02	-	
% Residential	6.52	0.01	+	
Road Density	6.88	0.008	+	
Fragmentation	7.08	0.007	+	

* = the number of underpasses visited by the species

Table 7. Significant underpass dimension and cover variables associated with the probability of a species using an underpass (n = 43) as determined by logistic regression analysis.

	x^2	p	Direction	#*
Bobcat:				20
% Natural Cover	4.17	0.04	+	
% Landscape Cover	4.52	0.03	-	
Gray Fox:				4
Length	4.78	0.02	-	
Width	10.82	0.001	+	
Height	12.56	< 0.001	+	
Openness	13.84	< 0.001	+	
Underpass Size	12.82	< 0.001	+	
% Natural Cover	8.81	0.02	+	
Opossum:				21
% Landscape Cover	4.19	0.04	-	
Mule Deer:				3
Height	3.65	0.05	+	
Openness	6.07	0.01	+	

* = the number of underpasses visited by the species

Table 8. Spearman rank correlations between landscape variables and the frequency of underpass usage.

	Visited Underpasses			All Underpasses (n = 43)	
	r_s	p	n*	r_s	p
Bobcat:			20		
% Wild				0.44	0.002
% Residential				-0.47	0.001
Corridor Width	-0.75	< 0.001			
Road Density	0.49	0.02		-0.33	0.02
Fragmentation	0.74	< 0.001		-0.30	0.05
Coyote:			25		
% Wild	-0.51	0.009			
% Urban Park	0.43	0.03			
% Residential	0.49	0.01			
Corridor Width				0.33	0.03
Road Density	0.47	0.01			
Fragmentation	0.46	0.01			
Gray Fox:			4		
Corridor Width				-0.47	0.001
Opossum:			21		
Fragmentation	0.43	0.05			
Raccoon:			14		
Corridor Width	-0.76	0.001		-0.37	0.01
Fragmentation	0.62	0.01			
Striped Skunk:			32		
% Wild	-0.46	0.007			
% Residential	0.45	0.009			
Corridor Width	-0.36	0.04			
Fragmentation	0.41	0.01			
Domestic Cat:			5		
% Residential	0.95	0.01			
Corridor Width	-0.87	0.05			

* = the number of underpasses visited by the species

Table 9. Spearman rank correlations between underpass dimension variables and the frequency of underpass usage.

	Visited Underpasses			All Underpasses (n = 43)	
	r_s	p	n*	r_s	p
Bobcat:			20		
Width	0.43	0.05			
% Natural Cover	0.73	< 0.001		0.45	0.002
Coyote:			25		
Width	0.45	0.02			
Height	0.44	0.02			
Openness	0.52	0.007		0.32	0.03
Gray Fox:			4		
Length				-0.32	0.03
Width				0.38	0.01
Height				0.34	0.02
Openness				0.42	0.004
Underpass Size				0.45	0.002
% Natural Cover				0.40	0.008
Opossum:			21		
Length	0.42	0.05			
% Natural Cover	0.46	0.03		0.33	0.03
Raccoon:			14		
Width	0.58	0.02			
Height	0.63	0.01		0.30	0.05
Mule Deer:			3		
Width				0.39	0.01
Height				0.43	0.004
Openness				0.41	0.006
Domestic Cat:			5		
Width				0.35	0.02
Height				0.31	0.03
Openness				0.30	0.05

* = the number of underpasses visited by the species

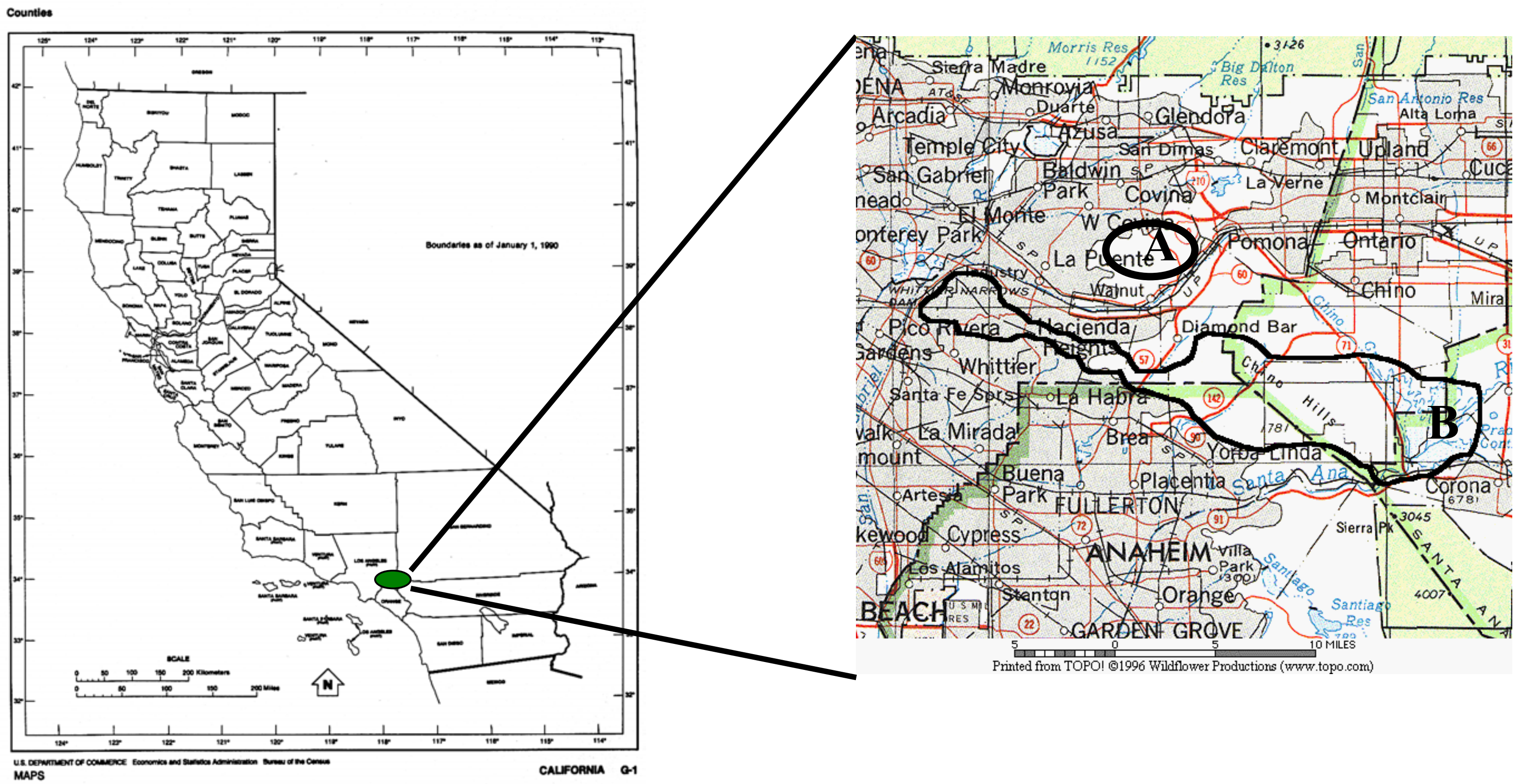

Figure 1. Location of study area in the Puente-Chino Hills, including the San Jose Hills (A) and Prado Flood Control Basin (B).