# Maintaining Ecological Connectivity Across the "Missing Middle" of the Puente-Chino Hills Wildlife Corridor


**Final Report**

**July 2005**


CONSERVATION BIOLOGY INSTITUTE

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July 2005

The Conservation Biology Institute provides scientific expertise to support conservation and recovery of biological diversity in its natural state through applied research, education, planning, and community service.

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# Acknowledgements

Conservation Biology Institute (CBI) thanks the following individuals and organizations for support and contributions to this report. Financial support was provided by Resources Legacy Fund Foundation, with special thanks to Maureen Rose and Ed Hastey. Rick Rayburn (California State Parks) was responsible for involving CBI in this important project and provided early guidance on its goals. Claire Schlotterbeck (Hills For Everyone) provided essential information, advice, contact information, and inspiration, and Melanie Schlotterbeck (The Trust for Public Land) provided GIS data, photographs, advice, information, contacts and other valuable input. Dan Wooldridge (Waters and Faubel) provided copies of various reports and plans reviewed in this report. Andrea Gullo and Amy Henderson (Puente Hills Landfill Native Habitat Preservation Authority) also provided data, reports, and other useful information. Geary Hund, Claire Schlotterbeck, Melanie Schlotterbeck, and Amy Henderson reviewed a draft of this report and offered valuable corrections and clarifications to the contents. The following CBI employees assisted in preparing this report: Heather Rustigian, with oversight from Jim Strittholt, prepared GIS maps and calculations; John Bergquist provided Keyhole screen captures used as illustrations; and Mike White and Jerre Stallcup reviewed and helped produce the report.

# Executive Summary

The Puente-Chino Hills Wildlife Corridor is a peninsula of mostly undeveloped hills jutting about 42 km (26 miles) from the Santa Ana Mountains into the heart of the densely urbanized Los Angeles Basin. Intense public interest in conserving open space here has created a series of reserves and parks along most of the corridor's length, but significant gaps in protection remain. These natural habitat areas support a surprising diversity of native wildlife, from mountain lions and mule deer to walnut groves, roadrunners, and horned lizards. But maintaining this diversity of life requires maintaining functional connections along the entire length of the corridor, so that wildlife can move between reserves—from one end of the hills to the other.

Already the corridor is fragmented by development and crossed by numerous busy roads, which create hazards and in some cases barriers to wildlife movement. Proposed developments threaten to further degrade or even sever the movement corridor, especially within its so-called "Missing Middle." This mid-section of the corridor system, stretching from Tonner Canyon on the east to Harbor Boulevard on the west, includes several large properties proposed for new housing, roads, golf courses, and reservoirs. Such developments would reduce habitat area and the capacity to support area-dependent species and, if poorly designed, could block wildlife movement through the corridor.

This report builds on an impressive array of previous ecological and wildlife movement studies in the Puente-Chino Hills, as well as the general literature on wildlife movement corridors as it applies to this unique peninsula of wildness. It supplements the existing information with an analysis of gaps in protection—with special focus on the vulnerable Missing Middle—and recommends conservation and management actions to prevent further loss of ecological connectivity and retain native species.

## *Methods*

I performed a meta-analysis of corridor function using existing scientific information on the distribution and movement patterns of wildlife species in the study area, as supplemented by field reconnaissance and examination of aerial and satellite imagery. Following the lead of previous researchers, I segmented the range of hills into nine geographic units by roads and other breaks in habitat contiguity. From southeast to northwest these are:

- A biological "core" area (defined below), represented by the Santa Ana Mountains;
- Seven segments of the functional Puente-Chino Hills Wildlife Corridor (from southeast to northwest: 1-Chino, 2-Carbon-Tonner, 3-Shell-Aera, 4-Powder-Schabarum, 5-San Miguel, 6-East Whittier, 7-West Whittier); and
- One isolated patch off the tip of the range of hills (Whittier Narrows), which is effectively disconnected from the functional corridor segments by major roads and urban barriers.

The Missing Middle consists of the western portion of Segment 2 (including the large and biologically diverse Tonner Canyon) and all of Segment 3 (Shell-Aera property and adjacent lands between Highway 57 and Harbor Boulevard). The eastern portion of Segment 2 (between Tonner and Carbon Canyons) is largely conserved already, but Tonner Canyon and Shell-Aera are unprotected and threatened by development projects.

Each of the nine geographic units was initially characterized for how it appears to function in supporting populations of target species, including mountain lion, mule deer, bobcat, coyote, coast horned lizard, and greater roadrunner, as well as in the richness of its reptile and amphibian community. The following coarse-scale definitions apply to these units:

- *Core* areas must be larger than 2,000 sq. km and capable of supporting a population of 20 adult mountain lions (the most area-dependent target species). Due to large size and relatively low "edge effects," a core area will support the greatest diversity of species and should support populations of all target species. The Santa Ana Mountains are the only core in the study area. This core serves as a source for mountain lions and other species to enter the corridor system.
- *Subcores* are smaller (but at least 60 sq. km) and capable of supporting a population of bobcats, the second-most area-dependent target species. Subcores can sustain populations of most target species and have moderate to high species diversity. Corridor Segment 1 (Chino Hills between Highways 91 and 142) is the only subcore, although Segment 2 appears to function as an extension of this subcore, as discussed below.
- *Patches* are smaller than 60 sq. km, but may support small numbers of bobcats and significant populations of other target species. Patches may also provide significant live-in or move-through habitat for mountain lions and bobcats, whose home ranges may cover multiple geographic units. Most segments in the corridor system are patches, but they vary greatly in size (from about 1.5 to 44.3 sq. km), vegetation composition, isolation by roads, and ability to support target species.

The roads delimiting these segments were next characterized for their effects on target species movements—as barriers, semi-permeable "filters," or highly permeable filters. Based on the scientific literature and field reconnaissance, each road was assessed for how easily target species can cross it, the availability and effectiveness of crossing structures (e.g., bridges and underpasses), and relative frequency of roadkill. Roads considered highly permeable to wildlife movement allow adjacent segments to function as one larger segment, such that two areas originally classified as separate patches may effectively serve as one larger patch (summing the area of adjacent units), or even a subcore, for certain target species.

I assigned each newly defined unit, or composite unit, a function relative to supporting individuals or populations of each target species based on unit size, habitat composition, and other factors, as follows:

- *Population* — capable of supporting a breeding population of at least 20 *adults* and potentially serving as a source of individuals that disperse into other units.
- *Subpopulation* — capable of supporting at least two but less than 20 breeding individuals. Subpopulations may exchange individuals with other areas within a larger metapopulation (a set of partially isolated populations linked by occasional dispersal) and may provide individuals to recolonize habitat patches in case of local extirpation.
- *Home Range Part* — incapable of supporting at least two breeding individuals on its own, but may provide live-in habitat (e.g., foraging or resting cover) and form a part of one or more individuals' home range(s).
- *Move-through* — not contributing significant live-in habitat for a species as part of a functional home range, but capable of accommodating movements between more substantial units within a home range, or potentially used for dispersal between other habitat units.

This system for characterizing geographic units and movement impediments was used to assess how the overall corridor system functions to support target species, and how these functions might change with potential development scenarios, such as new roads or housing that could add movement barriers or reduce wildlife carrying capacity in corridor segments.

## Results

### Existing Corridor Function

The Puente-Chino Hills Wildlife Corridor appears functional for at least larger mammals and birds, although tenuously so in the Missing Middle (due to several barrier or near barrier roads) and across smaller Segments 4 and 5 (due to their small size, strong edge effects, and high human and pet activity). Essentially all roads in the study area are considered barriers or at least strong filters to movements by many reptiles, amphibians, and small mammals; however, most birds and larger mammals currently can move between all segments either at-grade (with mortality risks) or via critical road-crossing structures. Despite many crossing constraints through the corridor, especially in and just west of the Missing Middle, target species are confirmed or highly likely to occur in all seven Puente-Chino Hills corridor segments, except for coast horned lizard, which may already be absent (or will disappear in the future) west of Highway 57.

Individual mountain lions are capable of traversing the length of the corridor, albeit at some risk of roadkill, and one or more lions still hunt as far west as the western Puente Hills (known locally as the Whittier Hills). Most other target species (e.g., bobcats, roadrunners) appear to persist throughout the corridor as metapopulations that are connected genetically and demographically by at least occasional dispersal between geographic units.

Carbon Canyon Road (between Segments 1 and 2) and Turnbull Canyon Road (between Segments 6 and 7) are considered highly permeable to at least larger mammals and birds, so I merged Segments 1 and 2 to form a larger Chino-Tonner subcore, and I merged Segments 6 and 7 to form a larger Whittier Hills patch. The most critical road-crossing structures are the Coal Canyon Wildlife Underpass (connecting the Santa Ana Mountains Core to the Chino Hills under Highway 91); a box culvert under Carbon Canyon Road known to be used by bobcat and other species; the Tonner Canyon Bridge on Highway 57 (the only viable crossing beneath this busy freeway for deer, mountain lion, bobcat, and other species); and the Colima Service Tunnel (used by bobcat, deer, coyote, and other species to cross under Colima Road between San Miguel Canyon and the Whittier Hills). In addition, a new wildlife tunnel is being built under Harbor Boulevard (between Segments 3 and 4) at a location well-documented as a roadkill "death trap."

There appears to be a gradient of declining amphibian and reptile diversity and evenness moving west from the Chino Hills, probably due to increasing edge effects coupled with increasing distance and number of barriers and filters that must be crossed the farther west one moves from source habitats in the east. A similar gradient may exist for other taxa, such as small mammals, that are similarly limited in their dispersal abilities.

Given the length of the corridor relative to species movement abilities, the capacity of corridor segments to support many species depends both on

- The potential for individual movement between each set of adjoining segments (a function of roads and road-crossings), and
- Having sufficient live-in habitat along the way to support populations or subpopulations that contribute dispersing individuals.

The greater a segment's distance from units supporting populations or subpopulations of a species, the lower the probability that the segment can continue supporting a species. If the distance between occupied segments becomes too great, or if barriers prevent inter-segment movement, local extinctions are inevitable in the isolated segments. Thus, any reduction in the capacity of segments to support populations or subpopulations increases the probability of local extinctions in that segment, as well as in all other "downstream" segments to the west.

Habitats in the Missing Middle are critical to maintaining overall corridor function. The Tonner Canyon area serves as an extension of the large Chino-Tonner subcore, with significant live-in habitat that can contribute dispersing animals to move into other segments. Likewise, Segment 3 (Shell-Aera) presumably supports significant numbers of target species that disperse (currently at some risk) across Harbor Boulevard into Powder Canyon (Segment 4) and beyond.

**Future Scenarios**

I assessed the likely effects of several proposed development projects in the Missing Middle on species persistence through the corridor system. This qualitative assessment uses the conceptual model developed above, based on how projects might affect the capacity of geographic units to support populations or individuals and the ability of individuals to cross between units. The projects include a new residential community, a series of reservoirs, and a major new road.

All three proposed developments have the potential to extirpate target species from large portions of the Puente-Chino Hills Wildlife Corridor. By impeding species movements or metapopulation dynamics, a project's impacts on species persistence may extend far beyond project boundaries, potentially rippling through the range of hills to eliminate wildlife populations as far west as the Whittier Hills (10-12 km west of the Missing Middle). The proposed Shell-Aera Master Planned Community would seriously degrade the ability of Segment 3, and all segments farther west, to support target species, especially mountain lion and bobcat. This would have cascading effects on flora and fauna in all segments from this point west.

A plan by the City of Industry to build three water reservoirs in Tonner Canyon could also have substantial adverse impacts on corridor function. Although a reservoir or other development in upper reaches of Tonner Canyon might not greatly affect corridor function, any development in middle and especially lower Tonner Canyon could have severe impacts on corridor function, especially if wildlife use of the Tonner Canyon Bridge (to cross Highway 57) is reduced. Any development that blocks access through the bridge area would make Highway 57 a complete barrier to many species and would likely lead to wildlife extirpations in segments farther west. At the very least, creation of these reservoirs would reduce the size of the Chino-Tonner subcore and its capacity as a source of animals that disperse into the rest of the corridor system.

Finally, plans by the City of Industry to build a new road running the length of Tonner Canyon could split the Chino-Tonner subcore in two, potentially isolating about 21.2 sq. km of habitat from this currently large and contiguous source habitat. The road would probably require major cut and fill to construct and could render disfunctional the critical Tonner Bridge wildlife undercrossing. This would almost surely result in the rapid loss of mountain lion and bobcat from more westerly segments, with cascading effects through the ecological community. Deer and other species would also likely disappear from westerly segments over a longer time period.

A full impact analysis for any of these proposed projects should address cumulative impacts on wildlife populations and movements through the corridor. Among these cumulative impacts would be inducement of further development, such as additional residential, commercial, or industrial development along the road. Increases in traffic and roadkill should also be analyzed and mitigated for. Any combination of two or more of these projects, even if well designed, would likely render the Puente-Chino Hills Wildlife Corridor non-functional west of Chino Hills State Park, regardless of mitigation.

## *Discussion*

The scientific literature on the functions and values of wildlife corridors is huge and growing. Movement corridors connecting reserves or larger "core areas" of habitat have been documented to counter many adverse effects of isolation by fragmentation on species and ecological processes. Some critics have argued that there are costs as well as benefits to conserving corridors and that, under certain circumstances, creating or maintaining corridors could harm some species or communities. However, the overwhelming weight of scientific evidence is that maintaining connectivity is beneficial, especially for those species and ecological communities for which connectivity "is the natural state of things." Most arguments against corridors boil down to nothing more than cautions against viewing them as conservation panaceas. Nevertheless, I reviewed the following arguments made against corridor conservation as they apply to the Puente-Chino Hills Wildlife Corridor:

1. Corridors may serve as conduits for the spread of deleterious species;
2. Corridors may spread detrimental processes, such as wildfire or disease, among reserve areas;
3. Corridors may facilitate movements by highly mobile and adaptable animals (like coyotes), but may not help more sedentary or at-risk species;
4. Corridors could attract wildlife into edge-affected habitats with high mortality rates; and
5. Corridor conservation may be more expensive or less beneficial than other options, such as increasing the size or management of core reserves.

Critical review of these concerns for the Puente-Chino Hills Wildlife Corridor finds them irrelevant or insignificant in this case; at least, the biodiversity benefits of conserving the corridor far outweigh any potential for harm.

Mitigating the adverse effects of roads, including barrier effects and increased mortality, is essential to maintaining corridor functions. The scientific literature on effective mitigation actions, especially wildlife road-crossing structures, is also large and growing, with many success stories. The main types of structures, from most to least effective, are vegetated land-bridges (wildlife overpasses), bridges, underpasses, and culverts. Vegetated overpasses are quieter than underpasses, maintain ambient conditions, seem less intimidating for some species than dark tunnels, and have proven highly successful in the U.S., Canada, and Europe for a wide variety of wildlife species. Bridges are also highly effective, especially if wide and open with natural vegetation growing beneath, such as under the Tonner Bridge. Culverts and other tunnel-like structures can be effective for some species, but only very large culverts (such as box culverts and equestrian tunnels) are effective for larger mammals. Earthen flooring is preferable to concrete or metal. Regardless of crossing type, wildlife fencing is crucial for keeping animals off the road and for funneling them toward the crossing structure. Vegetative cover near the entrances also increases wildlife use of crossing structures.

## *Conclusions and Recommendations*

Given the huge investment already made to maintain the Puente-Chino Hills Wildlife Corridor, additional conservation investment in the Missing Middle seems not only prudent, but essential if society believes the continued presence of deer, bobcats, roadrunners, and other wildlife is desirable in this unique peninsula of wild in a sea of development. My recommendations for how to do this are largely concordant with previous recommendations by other biologists.

I recommend conserving all of Segment 3 (the Shell-Aera property) and at least the middle and lower portions of Tonner Canyon, including prohibiting any new road or other development that would fragment this critical habitat block or degrade in any way the utility of the Tonner Bridge as a wildlife underpass. I also emphasize the following recommendations for improving road-crossing structures and reducing roadkill.

A. Add wildlife fencing on either side of Carbon Canyon Road to reduce roadkill and encourage wildlife to use existing culverts, especially the concrete box culvert near the entrance to Chino Hills State Park. Add another wildlife crossing structure (bridge or vegetated over-crossing), designed to accommodate all large mammals, as mitigation for any future road upgrades.

B. Prohibit any development that would increase traffic under the Tonner Bridge or add any new impediments (structures, lights, noise, etc.) to the vicinity of the bridge. Restore riparian vegetation along Tonner Creek, where degraded by oil development activities. Fence along Highway 57 if monitoring suggests road mortality is high.

C. Secure rights to install wildlife fencing along both sides of Harbor Boulevard to reduce roadkill and ensure maximum utility of the wildlife tunnel being built here. Plant screening vegetation on either side of the tunnel to provide cover to wildlife approaching the entrances.

D. Secure remaining "at-risk" parcels in the narrow, constricted portion of the corridor between Powder Canyon and Hacienda Boulevard. Enlarge or otherwise improve the existing equestrian tunnel under Hacienda Boulevard to enhance its use by wildlife, including adding screening vegetation on the western end. Add wing fencing on either side of the tunnel to help funnel wildlife to it. Do not fence extensively along Hacienda Boulevard, unless coupled with new crossing structures, because most large mammals currently cross at-grade. Consider building a wildlife overpass (a vegetated wildlife bridge) over Hacienda Boulevard, taking advantage of steep slopes rising up from either side of the road, as mitigation for any future road improvements that would increase traffic volume or speed.

E. Maintain and improve the Colima Service Tunnel as a critical wildlife underpass. Add fencing or screening vegetation if necessary, based on further site-specific inspection or monitoring. Limit actions that would increase disturbance in the vicinity of the Service Tunnel from sunset to sunrise, such as artificial lighting or nighttime traffic or recreational uses through the tunnel.

# Introduction

The Chino and Puente Hills form a peninsula of wild uplands that jut from the Santa Ana Mountains into the heart of one of the largest unbroken urban areas in North America (Figure 1). Created by shifting Earth plates, this peninsula of wild in a sea of development supports a surprising diversity of native wildlife. Mountain lions still hunt mule deer in the area's diverse mosaic of grasslands, chaparral, coastal sage, and oak and walnut woodlands; roadrunners, California gnatcatchers, northern harriers, and other birds in decline throughout Southern California still persist here; as does a remarkably rich reptile and amphibian fauna.

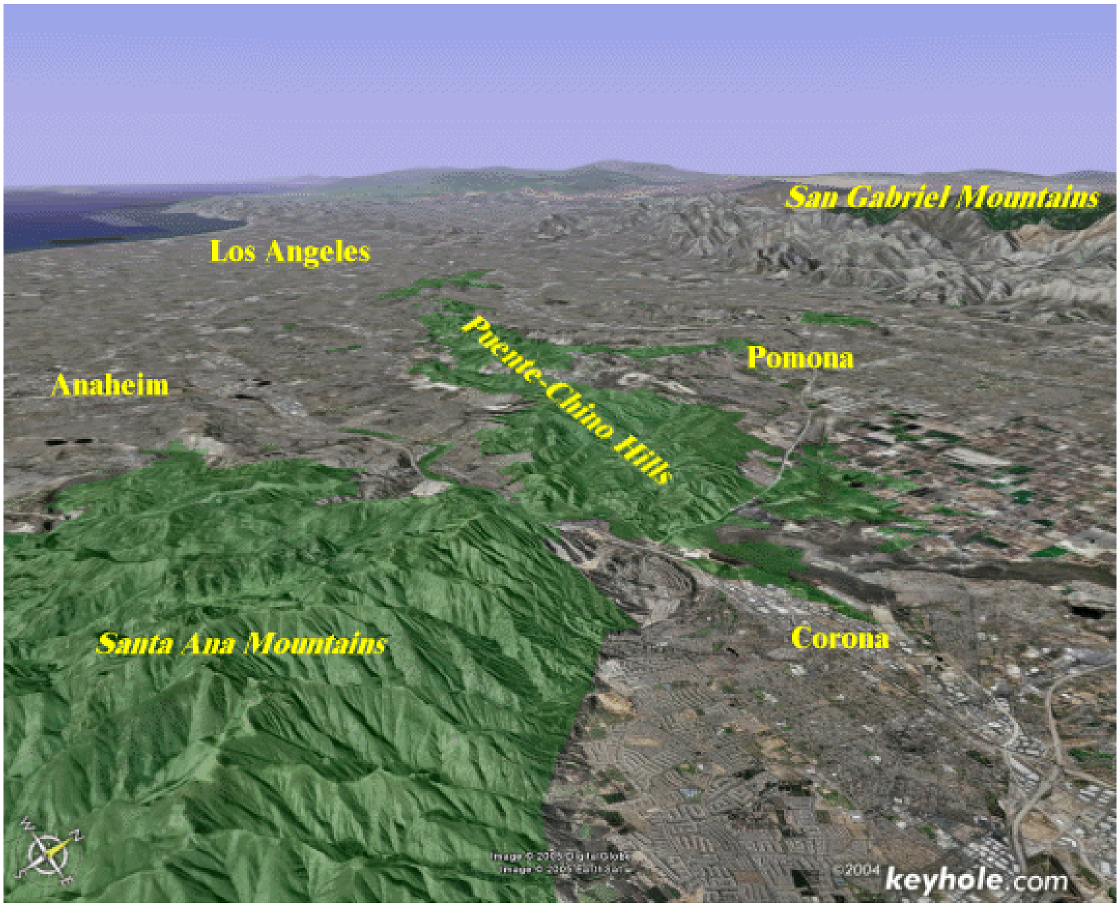



**Figure 1.** The Puente-Chino range of hills juts into the heavily urbanized Los Angeles Basin from the tip of the Santa Ana Mountains range (Keyhole screenshot).

Maintaining this diversity, and the web of healthy ecological interactions it represents, presumably requires keeping this range of hills fully connected by wild habitats along its 42 km (26 mi) length. Severing connections or blocking movement along this corridor with roads or housing projects threatens to extirpate species from this urban reserve system and degrade ecological health throughout this range of hills—thus eliminating a remarkable ecological classroom within easy reach of millions of people craving a connection with nature.

This loss would be doubly unfortunate given the tremendous public investment already made to conserve and restore biological open space and unfettered wildlife movement through this range of hills—from the Coal Canyon wildlife underpass at Highway 91, through Chino Hills State Park, Powder Canyon, Schabarum Park, and other private and public open space dedications to the western end of the Puente Hills (known locally as the Whittier Hills[1]). According to the California Department of Parks and Recreation, nearly a *quarter billion dollars* have already been expended or committed to acquiring and restoring natural open space in the Puente-Chino Hills Wildlife Corridor (http://hillsforeveryone.org/state_investment_table.htm). But the benefits of these existing investments is severely threatened by proposed development projects—including new roads, housing developments, golf courses, and reservoirs.

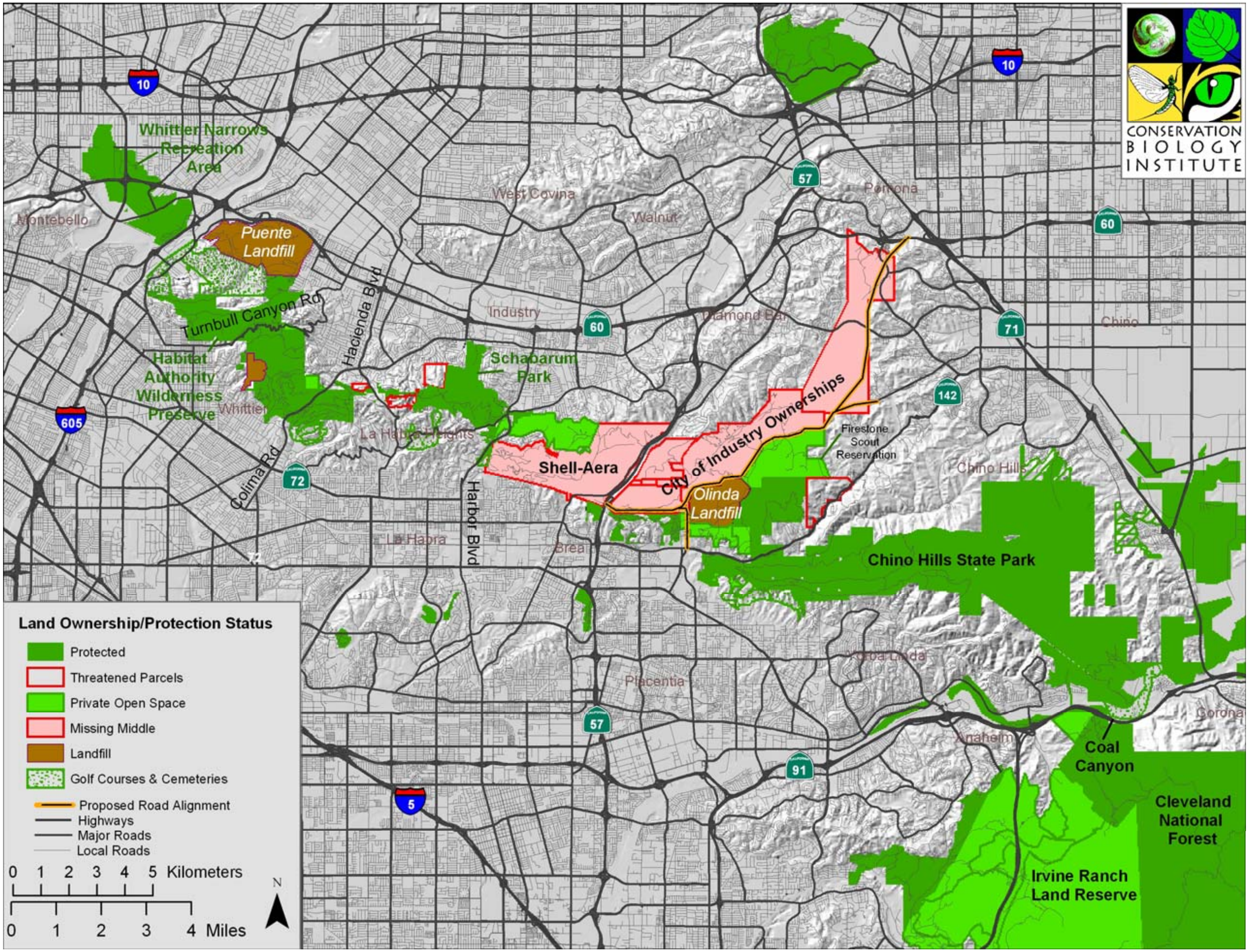
These threats are most urgent in the so-called "Missing Middle" of the corridor—from Tonner Canyon on the east (mostly owned by the City of Industry) to Harbor Boulevard on the west (Map 1). No major reserves are yet established in this broad midsection of the Puente-Chino Hills, and connectivity is threatened by a major new housing development, a proposed road, and a series of new dams and reservoirs that would flood Tonner Canyon. Should one or more of these projects sever functional connectivity, reserves farther west (e.g., Habitat Authority Wilderness Preserve, Powder Canyon, and Schabarum Regional Park, among others) could lose key species and suffer further ecological degradation.

This report reviews available scientific evidence on wildlife movement corridors, reserve design, and local biological resources to define conservation priorities for maintaining connectivity from one end of the corridor to the other. It focuses on the Missing Middle, because this portion is least protected and is at most immediate risk of further degradation. The purpose of this analysis is to identify (a) those portions of the Missing Middle whose conservation would most contribute to continued wildlife movement and ecosystem health throughout the corridor system, and (b) remedial actions that would most improve the situation for native wildlife—such as retrofitting existing roads with wildlife crossing structures to reduce roadkill and improve movement opportunities.

## Report Objectives

- Synthesize the science of wildlife movement corridors as it pertains to the Puente-Chino Hills Wildlife Corridor.
- Analyze existing conditions and potential future conditions for the persistence and movement of wildlife populations in the corridor system.
- Recommend conservation and management priorities to sustain and improve connectivity through the Missing Middle and hence the greater Puente-Chino Hills Wildlife Corridor.

[1] Although "Whittier Hills" is not an official geographic name recognized by the U.S. Geological Survey, the western portion of the Puente Hills is known locally as the Whittier Hills, and previous researchers have used this place name. I therefore also use Whittier Hills to refer to the hills west of Colima Boulevard.




Map 1. Study area showing the Missing Middle of the Puente-Chino Hills Wildlife Corridor.

# Study Area

This study considers two nested study areas (Map 1): the entire Puente Hills-Chino Hills Wildlife Corridor, extending about 42 km from the Santa Ana Mountains to the San Gabriel River, and the so-called "Missing Middle" of this larger landscape. The Missing Middle is that section of the Puente-Chino Hills Wildlife Corridor from Harbor Boulevard on the west to and including Tonner Canyon on the east. The Missing Middle is largely unconserved and is threatened by a variety of development projects.

## *Biogeography*

The Puente-Chino Hills are the northernmost extension of the Peninsular Mountain Range, which begins in Baja California, Mexico. They are a topographic expression of the 500-km-long Whittier-Elsinore fault system, pushed up between the Whittier and Chino sections of this major slip-shear fault system. The geologically dramatic origins of the hills also contribute to their relatively undeveloped status, because steep slopes, earthquakes, landslides, tar pits, and active and former oil wells have tended to limit development, at least until recently.

The hills rise from the flat Los Angeles Basin, at less than 100 m (300 ft) elevation, to over 540 m (nearly 1,800 ft) at San Juan Hill. The regional climate is mild and Mediterranean, which contributes to the high diversity of species in coastal Southern California. Vegetation in the hills is a mosaic of open grasslands (which have been affected by grazing over the years), coastal sage scrub, chaparral, oak woodlands, riparian scrub, riparian woodlands, and rare California black walnut woodlands—a grossly under-protected resource that could be considered an "endangered habitat." These communities support flora and fauna relatively typical of the biodiversity in Southern California—which is remarkable given that the hills are entirely surrounded by the largest urbanized area in the U.S.

## *Previous Studies*

The Puente-Chino Hills represent one of the most closely scrutinized and intensively researched wildlife movement corridors in Southern California, if not North America. Its existence and importance are well appreciated by the local populace, with 53% of local residents having "heard of the wildlife corridor in the Puente Chino Hills area" and 83% in favor of maintaining the corridor (51% "strongly" supported this) (Decision Research 2003). The area's flora, fauna, and ecological functions are well studied, with a number of intensive studies of wildlife distributions and movements covering all or substantial portions of the area (Table 1). In 1994 an entire scientific conference was focused on the biological functions and values of this unique range of hills (Natural Resources in the Puente Hills-Chino Hills Corridor: Implications for Land Use and Planning. A symposium at Whittier College, March 18-19, 1994)[2].

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[2]Abstracts of papers presented at this conference can be found at http://www.hillsforeveryone.org/PDF_Files/whittier_college_symposium.pdf.

**Table 1.** Summary of previous studies of wildlife populations and movements in the Puente-Chino Hills study area.

| Reference | Target Species | Major Focus | Study Area | Methods | Relevant Results | Recommendations |
|---|---|---|---|---|---|---|
| Robertson et al. 1995 | Large mammals | Assess likely movement routes and constraints. | Entire Puente-Chino Hills Wildlife Corridor from the Santa Ana River to the San Gabriel River. | Field reconnaissance, walking the length of the corridor to assess likely movement routes and constraints. Incidental observations of wildlife sign and roadkill. | At least one pathway without complete obstruction existed for large mammals, from the Santa Ana River to the Whittier Hills, in 1994-95, but with several significant constraints. The most critical impediment was Harbor Blvd. and adjacent development. Movement across Interstate 605 to the San Gabriel River (Whittier Narrows Recreation Area) considered "highly improbable." | Conserve land to connect existing reserves (especially in the middle portions of the Corridor); restore native vegetation; retrofit undercrossings at problem roads, especially Harbor Blvd., with tunnels or bridges to reduce roadkill and improve connectivity for large mammals. |
| Noss et al. 1997 | All vertebrate wildlife | Assess importance of Coal Canyon linkage to maintaining viable species populations in the Santa Ana Mountains and Puente-Chino Hills. | Entire Puente-Chino Hills Wildlife Corridor and Santa Ana Mountains. | Literature review, field reconnaissance, and analysis of which species' populations were likely to benefit from protecting and improving the Coal Canyon linkage and underpass. | Coal Canyon is the last viable linkage between the Chino Hills and Santa Ana Mountains. At least 21 vertebrate species have populations <500 individuals in the Puente-Chino Hills, and at least four of these have <50 breeding adults. Risks of extirpation from the hills would increase for all these species in the absence of the Coal Canyon corridor. The corridor also benefits species in the Santa Ana Mountains, especially the mountain lion and several grassland species. Mountain lion and bobcat would likely be the first species adversely affected by loss of the corridor. | Protect and restore a functional undercrossing at the Coal Canyon interchange with Highway 91. Remove pavement and restore natural soils, vegetation, and drainage through the undercrossing, and install wildlife fencing to funnel wildlife off the highway and through the underpass. |

Table 1. Continued.

| Reference | Target Species | Major Focus | Study Area | Methods | Relevant Results | Recommendations |
|---|---|---|---|---|---|---|
| Haas and Crooks 1999, Haas 2000, Haas and Turschak 2002 | Large and medium-bodied mammals | How landscape variables and underpass characteristics affect the distribution and relative abundance of target species in the study area, and the frequency of underpass usage by each species. | Entire Puente-Chino Hills Wildlife Corridor, from Santa Ana River to Whittier Hills. | *Field methods*: scat transects, remote-triggered camera stations, and baited track stations. *Statistical analyses:* Correlated probability and frequency of species use with landscape variables (e.g., corridor width, % wild) and underpass characteristics. | Bobcat and long-tailed weasel were negatively associated with habitat fragmentation. Fragmentation was negatively associated with probability of underpass usage by coyote, bobcat, and long-tailed weasel, and negatively associated with the frequency of use by bobcat. Underpass dimensions were important in determining probability of use by deer and gray fox, and with frequency of use in coyote, gray fox, deer, and domestic cat, with more open underpasses used most. 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 an underpass being used depends primarily on landscape characteristics, while its frequency of use depends primarily on underpass dimensions. | Bobcats are an excellent target species for conservation in the study area. Habitat acquisition and restoration should be concentrated in the narrowest portion of the corridor and at chokepoints along roadways. Existing underpasses should be surrounded by natural cover and use fencing to direct wildlife under the roadway. Future underpasses should be large and situated as far from residential areas as possible. |

Table 1. Continued.

| Reference | Target Species | Major Focus | Study Area | Methods | Relevant Results | Recommendations |
|---|---|---|---|---|---|---|
| Cooper 2000 | Breeding birds | Determine distribution of breeding land birds to identify priority conservation areas. | Entire Puente-Chino Hills Wildlife Corridor, from Santa Ana River to Whittier Hills. | Point counts and walking transects to determine presence/absence. | California gnatcatcher, cactus wren, and other rare or declining species documented in diverse locations. Greater roadrunner widespread but not common; most commonly observed in middle portions of the Corridor. California quail found throughout study area except smallest fragments. Burrowing owl apparently extirpated from the study area during the 1990s. Several areas of high-quality habitats supporting diverse avifauna identified. | Conserve three priority areas based on size, threats, and support of declining species: (a) coastal sage scrub in northern Brea and Yorba Linda (southern portion of Missing Middle); (b) extensive grassland and savannah south of Rowland Heights (northern portion of Missing Middle); (c) grasslands of upper Tonner Canyon (northeastern portion of Missing Middle). |
| PCR et al. 2000 | General wildlife | Analyze the Puente Hills area as a Significant Ecological Area (SEA) recognized by the County of Los Angeles. | That portion of the study area within Los Angeles County, from the Whittier Narrows to Tonner Canyon. | No original field studies; review and analysis of existing information. | The area meets several designation criteria as an SEA, including that it is regionally important to many resident and migrating species, especially large mammals, wintering raptors, and songbirds, in large part due to regional connectivity. | Retain connectivity and linkage values between major canyons of the SEA, and especially at choke points and major road crossings. |

Table 1. Continued.

| Reference | Target Species | Major Focus | Study Area | Methods | Relevant Results | Recommendations |
|---|---|---|---|---|---|---|
| Lyren 2001 | Coyotes and bobcats | Home range and movement characteristics, roadkill, and underpass use by bobcats and coyotes. | Primarily along SR 71 and adjoining areas occupied by telemetered animals. | Radio telemetry (29 coyotes, 4 bobcats); roadkill surveys along SR-71. | Home ranges of about half of all telemetered animals overlapped SR-71, indicating frequent road crossing by individuals. Most animals crossing the road were documented using underpasses; coyotes used underpasses more than bobcats. Coyote use of underpasses seemed suppressed by traffic volume. No bobcats were found road-killed; coyotes frequently were road-killed, with concentrations where no wildlife fencing was present along road. | Wildlife fencing should be used to funnel wildlife to underpasses. |
| Schlotterbeck 2001 | Large and medium-bodied mammals; reptiles and amphibians. | Assemble existing data from Haas and Crooks 1999 and Case and Fisher 1998 into a GIS database. | Entire Puente-Chino Hills Wildlife Corridor, from Santa Ana River to Whittier Hills. | No original field studies. Interviews with previous researchers and compilation and analysis of existing field data. | See entries for Haas and Crooks (1999) and Case and Fisher (1998) below. A comprehensive GIS database of their results was made available for research and monitoring. | Conservation and restoration of numerous lands, and proper management of these lands, is essential to stave off further species losses and ecological collapse in the Puente and Chino Hills. |

Table 1. Continued.

| Reference | Target Species | Major Focus | Study Area | Methods | Relevant Results | Recommendations |
|---|---|---|---|---|---|---|
| Haas et al. 2002, Case and Fisher 1998 | Reptiles and amphibians | Determine distribution and diversity of herpetofauna; identify management needs to maintain diversity. | Scattered locales across the Puente-Chino Hills Wildlife Corridor, from Chino Hills State Park to Whittier Hills. | *Field methods:* Pitfall drift-fence arrays and snake traps. *Statistical analyses*: Several measures of species richness and diversity analyzed relative to landscape position. | Species richness and diversity were generally highest in the Chino Hills (22 species) and Whittier Hills (14 species), with lower levels in the narrower, more fragmented areas between (10-12 species). The number of sensitive species declined from seven in the Chino Hills to four in the Whittier Hills, and the western limit for some species lies somewhere between Chino Hills and Whittier Hills. Several species (e.g., coast horned lizard, western skink, red diamond rattlesnake) showed decreased population densities moving west through the corridor. | Maintain habitat linkages to maintain gene flow and reestablishment of populations if localized extinctions occur. |
| PCR 2002 | General wildlife, with focus on large mammals. | Assess onsite biological resources and wildlife movement corridors to understand constraints to development on the Shell-Aera property. | Shell-Aera property and immediate vicinity; representing the western half of the Missing Middle (between SR-57 and Harbor Blvd.). | Sign reconnaissance; unbaited track stations, camera stations, and scat surveys focused on expected corridors and bottlenecks, such as road crossings; analysis of roadkill records. | Documented use of Shell-Aera property by deer, bobcat, coyote, roadrunners, and other native wildlife. Greatest evidence of wildlife movement was concentrated from the southeast corner of the property (associated with Tonner Bridge) to the northwest corner (associated with Drainage 26 and an area of high roadkill on Harbor Blvd.). Documented primary and secondary movement corridors across the property. | N/A--This biological constraints analysis describes existing conditions on the property and does not present recommendations. |

# Methods

This study synthesized and updated existing information on wildlife distribution and movements in the Puente-Chino Hills Wildlife Corridor (see Table 1) to serve as a "meta-analysis" of overall corridor function and of the role that each portion of the corridor plays in supporting native wildlife and wildlife movement. After analyzing existing conditions, I also considered how land-use changes in the Missing Middle could affect the continued persistence of wildlife populations throughout the corridor and in each portion of the corridor. The analytical process involved

1. Selecting a suite of target species for which there is sufficient local information to assess distribution and movements;
2. Defining geographic units of the corridor system and assessing their functions in supporting these target species;
3. Assessing the roads that segment the study area as potential barriers or filters to movement; and
4. Assessing how the current functionality of these segments could change with various development scenarios.

## *Reconnaissance*

The analysis of existing literature was supplemented with reconnaissance surveys in the field as well as using satellite imagery, high-resolution aerial photographs, and digital photographs taken during flyovers by Melanie Schlotterbeck. In particular I used the Keyhole program (www.keyhole.com) to perform a "virtual reconnaissance" of the study area, including properties where physical access was not possible. Keyhole[3] allows a user to zoom, pan, tilt, rotate, and otherwise explore a three-dimensional digital model of the Earth's surface covered with high resolution satellite imagery (2004-5 color images at 1-m resolution) and Geographic Information System (GIS) data that can be layered onto this imagery. This proved to be an ideal tool for "exploring" the terrain prior to the field visit, and while reviewing previous studies in the area, to determine how topography, vegetation, development, and other landscape features might influence target species movements. By zooming in, rotating, tilting, and moving along this virtual landscape, a wildlife biologist can readily see where steep terrain, road cuts, bridges, vegetation, housing developments, and other landscape features would tend to funnel movements by larger species across the study area. (For example, I predicted, based on Keyhole reconnaissance, that the stretch of Harbor Boulevard just south of Wellington Lane would be a deadly road crossing for large mammals, which was later confirmed by personal observations in the field and my literature review.)

[3] Reduced-resolution screen captures of Keyhole imagery are used to illustrate landscape issues throughout this report.

After extensive exploration of the study area using Keyhole, GIS, and high-resolution aerial imagery, I visited the study area on March 2, 2005. I drove all roads crossing the area, stopping to investigate road-crossing structures (bridges, culverts, etc.), walking sections of trails, and looking for wildlife and wildlife sign. I photographed key locations, roadkills, habitat conditions, and other pertinent scenes, and noted signs of wildlife on aerial photographs. Because my fairly cursory field observations strongly reinforced the quantitative results of more intensive studies (see Table 1), they are not presented in detail, but are cited as supporting or supplemental evidence for the results and recommendations of these previous studies.

## Target Species

It is important to clearly define what species and ecological processes are expected to benefit from a wildlife movement corridor (Rosenberg et al. 1997, Beier et al. in press). Target species were selected based on data availability (see Table 1) and how well they reflect overall corridor function or serve as indicators of habitat fragmentation and movement constraints. They include species that require large areas to survive, are most susceptible to extirpation by habitat fragmentation, are most susceptible to roadkill, or for which roads may serve as physical barriers. In addition, previous studies provide some more general measures of ecosystem health and corridor function, such as species richness for amphibians and reptiles (Haas et al. 2002) and avifauna (Cooper 2000).

Although it is tempting to think of one or a few larger mammal species as most obviously served by movement corridors, the ecological effects are far broader than any single species or set of species. Ultimately, the objective of securing and managing the Puente-Chino Hills Wildlife Corridor is more than ensuring that mountain lions can continue roaming the area (although that is certainly one objective)—it is ensuring that healthy ecological communities can continue to thrive and support the broadest possible range of native species.

### *Mountain Lion*

The mountain lion or puma (*Puma concolor*) is the top carnivore in Southern California. It is a true "keystone" species whose presence helps maintain ecological balance by controlling populations of deer and other prey (Soulé and Terborgh 1999, Crooks and Soulé 1999). Mountain lions require huge contiguous habitat blocks to persist, with individual lions roaming home ranges as large or larger than the entire Puente-Chino Hills study area. Only contiguous habitat areas large enough to support at least 20 individuals—about 2,000 sq. km in Southern California—are expected to support lion populations over even the short term (Beier 1993, Beier et al. in press). Due to demographic instability and inbreeding concerns, even populations meeting these criteria, such as the population of about 20 adult lions occupying the 2,070-sq.-km Santa Ana Mountains Range, must be connected to even larger populations for long-term persistence (Beier 1993).

Although the Puente-Chino Hills are too small (at about 163 sq. km) to support a population of mountain lions on their own, one to several lions live totally or partially within the hills as an extension of the larger Santa Ana Mountains population (Beier 1993, Noss et al. 1997). The Coal Canyon wildlife underpass on Highway 91 was restored specifically to ensure the continued presence of these large predators in the Puente and Chino Hills, thus ensuring a more healthy and balanced ecosystem (Noss et al. 1997). Lions have been detected all the way to the westernmost portions of the corridor (Whittier Hills) in recent years (A. Henderson, A. Gullo, and C. Schlotterbeck, personal communications).

Lions are very prone to roadkill. During Beier's (1993, 1995) study of mountain lions in the Santa Ana Mountains, vehicles killed 33% of the population, including four lions killed at one road-crossing during a 2-year period. Thus, mountain lions are good focal species for conservation planning in the study area, due to their keystone status, large area requirements, dependence on intact corridors, and susceptibility to roadkill.

*Bobcat*

Bobcats (*Lynx rufus*) are excellent indicators of functional landscape connections at the scale of interest in the Puente-Chino Hills study area (Crooks 2002, Haas 2002, Tigas et al. 2002, Riley et al. 2003). In Southern California, bobcat home ranges average about 2 to 6 sq. km, and population densities average about 1.1 to 1.6 bobcats per sq. km (Riley et al. 2003, Lembeck 1978, Lyren 2001). The probability of bobcat occurrence in a habitat patch is directly related to both the size of the patch and its isolation from other patches (Crooks 2002), with patches as small as 10 sq. km highly likely to support a few individuals if they are close enough together (within 1 km or less) and adequately connected to allow inter-patch movement (Crooks 2002). Using radio telemetry in the Santa Monica Mountains, Riley et al. (2003) found habitat blocks as small as 3.15 sq. km to support a few individuals, as long as movement was possible to larger, source population areas. Taking into account variation in habitat quality, Beier et al. (in press) concluded that contiguous habitat blocks of about 60 sq. km are necessary to support potential source populations of 20-25 adult bobcats over the short term in Southern California. Noss et al. (1997) estimated that a population of less than 50 bobcats inhabited the Puente and Chino Hills and less than 500 bobcats inhabited the Santa Ana Mountains. Haas (2002) found bobcats to be associated with wider portions of the Puente-Chino Hills, with lower densities in narrower segments. He concluded that bobcats used smaller segments primarily as "move-through" rather than "live-in" habitat.

Bobcats are behaviorally secretive and tend to avoid roads and other human disturbances, although they remain quite susceptible to roadkill. Bobcats are less likely to use road underpasses than coyotes, especially narrow underpasses or underpasses near residential areas, and so may be better indicators of high-quality road-crossing structures for wildlife.

*Coyote*

Coyotes (*Canis latrans*) are more adaptable, more abundant, and less averse to fragmentation than bobcats and mountain lions—and thus less dependent on high-quality landscape connections. Nevertheless, coyotes are important to maintaining ecological balance (Crooks and

Soulé 1999) and are good indicators of problem road-crossings, as many are killed on roads in the study area and elsewhere (Lyren 2001, Haas 2000, Robertson et al. 1995). Concentrations of coyote roadkills provide good indicators of potential crossing locations for other species, including bobcats, mountain lions, and mule deer. Noss et al. (1997) estimated a carrying capacity of roughly 60 adult coyotes for the Puente and Chino Hills and less than 500 in the Santa Ana Mountains.

*Mule Deer*

Mule deer (*Odocoileus hemionus*) are the primary prey of mountain lions and require relatively large habitat areas to support populations. Although they adapt to living in close proximity to humans, and are found in portions of the study area that are effected by fragmentation and development edges (Haas 2000), they are prone to roadkill and highly selective of road-crossing structures. In general, deer will use only the largest, most open types of structures (bridges or very open box culverts) within well-vegetated habitat areas to cross under (or over) roads (Haas 2000, Clevenger and Waltho 1999, Evink 2002). Noss et al. (1997) estimated that about 400 mule deer may inhabit the Puente and Chino Hills and about 4,000 may inhabit the Santa Ana Mountains.

*Greater Roadrunner*

Greater roadrunners (*Geococcyx californianus*) are associated with coastal scrub and open brush mosaics in coastal Southern California. They are highly susceptible to roadkill (Unitt 2004) and particularly sensitive to habitat fragmentation, rapidly disappearing from isolated habitat patches (Unitt 2004, Crooks et al. 2001, Soulé et al. 1988, Garrett and Dunn 1981). Soulé et al. (1988) and Crooks et al. (2001) identified the roadrunner as the most sensitive to habitat fragmentation of eight scrub-dwelling species they addressed in San Diego County. Crooks et al. (2001) found roadrunners persisting in only one of 34 canyons isolated by urbanization, and estimated that the roadrunner has a good chance of persisting only in patches 1.6 sq. km or larger. Based on more exhaustive surveys, Unitt (2004) concluded that this underestimates roadrunner sensitivity to isolation; he suggested that even 4.0-sq. km patches may be too small to sustain populations for long. As snakes and lizards are important prey, roadrunners may decline with reductions in reptile diversity and abundance.

Cooper (2000) reported that roadrunners are scattered in association with scrub habitats throughout the Puente-Chino Hills study area, with particular concentrations in the hills north of Brea and Yorba Linda (including significant portions of the Missing Middle). He estimated there were more than 50 breeding pairs (100 adult individuals) living in the Puente and Chino Hills.

*Coast Horned Lizard*

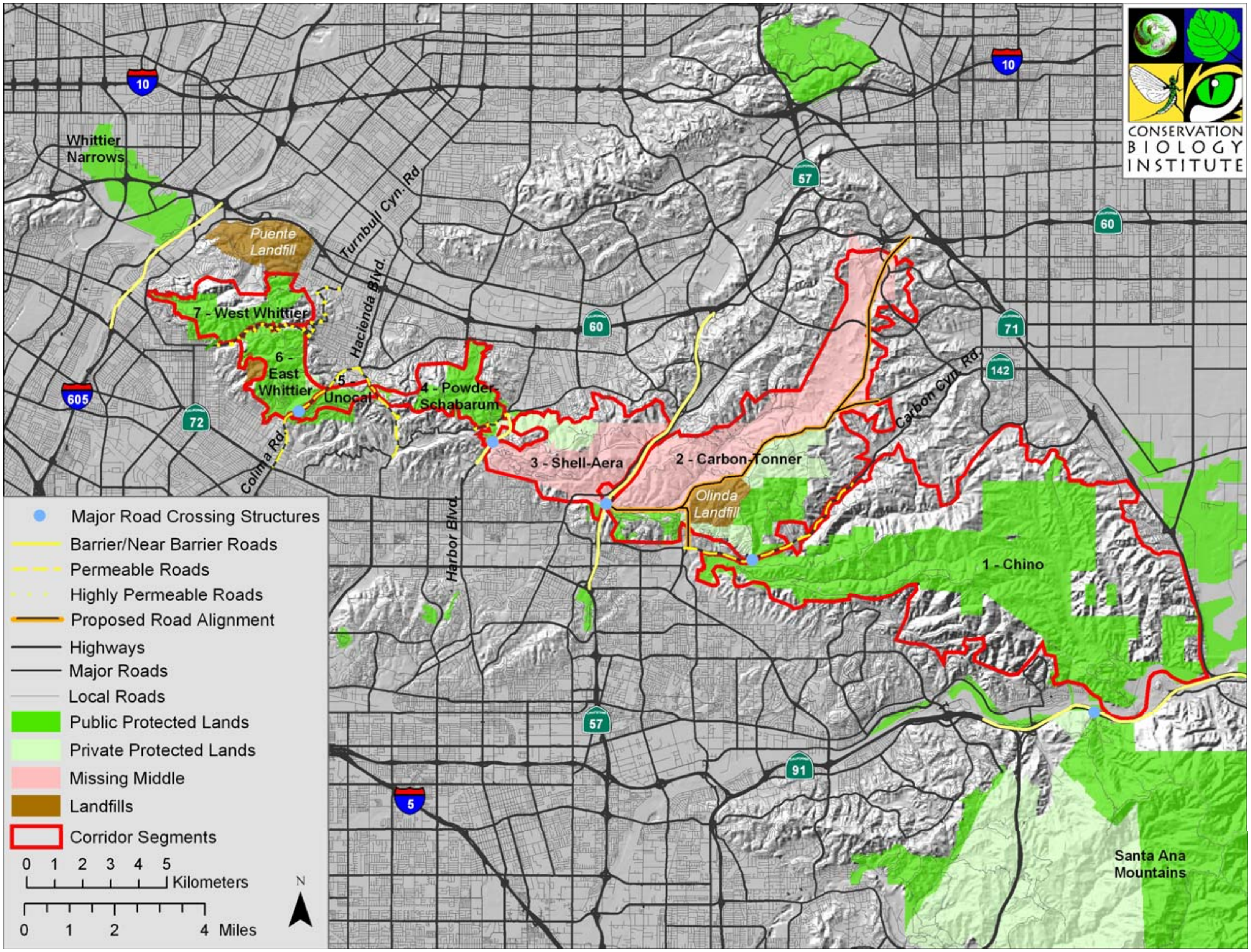
The coast horned lizard (*Phrynosoma coronatum*) was once common and widely distributed in coastal sage and chaparral habitats of Southern California, but has been extirpated from much of its former range by habitat loss and fragmentation (Fisher et al. 2002). This species is highly impacted by edge effects, such as invasions by the nonnative Argentine ant, which eliminates the native harvester ants that comprise more than 95% of the horned lizard's diet (Suarez et al. 2000). Argentine ants are closely associated with human-altered (especially irrigated) landscapes in Southern California, but can invade hundreds of meters into native scrub habitats; their adverse effects on native invertebrate populations ripple through the ecological community with devastating effects on biological diversity (Suarez et al. 1998). Thus, horned lizards serve as good indicators of relatively intact ecological webs and processes or, conversely, of the adverse effects of habitat fragmentation and edge effects on ecological communities (Fisher et al. 2002). They are also highly susceptible to roadkill and trampling. Case and Fisher (1998) and Haas et al. (2002) found coast horned lizards in the Chino Hills, as far west as the ridges between Carbon Canyon and Tonner Canyon (near the Olinda Landfill), but did not detect them at points farther west. Therefore, this species may already be extirpated, or likely will be soon, in corridor segments west of Highway 57 due to isolation of populations by roads and high mortality in remaining habitat areas.

*Other Target Resources*

The above target species certainly do not comprise a complete list of resources subject to loss due to habitat fragmentation and associated effects. They serve as indicators for a much more diverse community of organisms, and were chosen largely on this basis as well as the availability of distribution data in the study area. In addition to these species, I examined information on the diversity and abundance of reptiles and amphibians (from Case and Fisher 1998, Haas et al. 2002) and birds (Cooper 2000), and considered, at least qualitatively, the effects of habitat fragmentation on other species and ecological processes in the study area.

## Defining Geographic Units, Barriers, and Filters

Although the entire study area serves as a wildlife movement corridor at a gross scale, it functions more like a peninsula of somewhat discrete habitat blocks segmented by roads and other discontinuities (Haas 2000, Haas and Crooks 1999, Schlotterbeck 2001, Robertson et al. 1995). The Puente-Chino Hills Wildlife Corridor was therefore subdivided into discrete geographic units based on habitat contiguity and intervening roads. Each unit, including the Santa Ana Mountains (the core area from which the corridor system projects) and the isolated terminal segment at the Whittier Narrows (Robertson et al. 1995), was given a geographic name to facilitate comparison (Map 2). Following Haas and Crooks (1999), the seven units between these two extremes (or between Highway 91 and Interstate 605) were also numbered 1 to 7, from east to west. These seven segments comprise the functional Puente-Chino Hills Wildlife Corridor system. They are convenient for comparing results across the various field studies and for assessing how each segment, and the habitat breaks between them, contribute to overall functionality of the corridor system. These segments are therefore useful tools for conservation planning.




Map 2. Geographic units of the Puente-Chino Hills Wildlife Corridor.

*Initial Classification of Geographic Units*

Each geographic unit was first classified by the primary role it appears to play in the overall functioning of the wildlife corridor system—as a biological *core*, *subcore*, *patch*, or *isolate*. These functional categories, defined below, reflect the relative size and contiguity of the units and their ability to sustain populations or facilitate movements of target species, as supported by literature and results of previous wildlife studies here. These definitions are tailored to this particular study, based on well established conventions in reserve design (e.g., Noss 1987, Meffe and Carroll 1997, Soulé and Terborgh 1999), and modified slightly from concepts and definitions developed for the South Coast Missing Linkages project—a science-driven approach to conserving landscape connectivity throughout the South Coast ecosystem (Beier et al. in press). The most significant deviation from the definitions of Beier et al. (in press) is the inclusion of an intermediate-sized "subcore" class (which corresponds to a "patch" in Beier et al. in press).[4]

- *Core* — A core area must be large enough (> 2,000 sq. km) to sustain populations of most or all target species without the need for frequent immigration from other areas, and should have relatively high biological diversity and a low proportion of edge. Core areas support source populations of target species, which may contribute individuals to other, less substantial, blocks of habitat. Basically, a core should be large enough to support a population (at least over the short term) of the most wide-ranging and area-dependent target species, which in this case is the mountain lion.

- *Subcore* — Subcores are contiguous blocks of habitat at least 60 sq. km, but less than 2,000 sq. km (corresponding to a "patch" as defined by Beier et al. in press). Subcores are too small to sustain a population of mountain lions in isolation, but large enough to support a population of bobcats with at least occasional dispersal. Subcores may support one or a few individual mountain lions, or at least provide significant "live-in" habitat as part of one or more lion home ranges. Subcores are more edge-effected than cores and may sustain lower overall species diversity, but can nevertheless represent significant source populations for numerous other target species, such as roadrunners, coyotes, and horned lizards.

- *Patch* — Patches, at less than 60 sq. km, are smaller and more edge-effected than subcores and are expected to support overall lower numbers and diversity of species. In isolation, patches may be too small to support a population of bobcats, and perhaps other target species having intermediate area requirements, although they could support a small number of such species or at least represent live-in or move-through habitat for individuals of such species. Although they may support populations of less area-

[4] Concepts like "core" and "corridor" are species- and scale-dependent, such that what might be considered a movement corridor for one species (e.g., mountain lion) can be core "live-in" habitat for other species (e.g., lizards, songbirds, or rodents). This entire study area is widely recognized as a "wildlife corridor," even though numerous on-the-ground travel routes, population concentrations, etc., can exist within this overall corridor system at finer resolution.

dependent target species, patches may serve mainly as dispersal stepping stones (or "move-through" habitat) for individuals of larger species (like mountain lions) moving between larger geographic units.

- *Isolate* — An isolate is any patch that is separated from another geographic unit by barriers to movement for target species. For example, the Whittier Narrows are separated from the Whittier Hills by Interstate 605, other significant roads, and commercial development, and are considered functionally isolated from the corridor for nearly all reptiles, amphibians, and mammals (Haas and Crooks 1999, Haas et al. 2000, Robertson et al. 1995, personal observations).

Note that these initial landscape categories were defined based primarily on the needs of the most area-dependent target species (mountain lion and bobcat). However, such concepts as "core" and "patch" can also be defined separately for each target species, based on their own requirements. Thus, a patch of habitat too small to support mountain lions could represent a "core" population area for less area-dependent species, like the roadrunner or horned lizard. Such species-specific issues were treated in more detail in later analytical steps.

*Classifying Barriers and Filters to Movement*

Roads and other discontinuities in habitat were also classified based on their relative effects on movements and population distributions of species, as follows:

- *Barriers* and *Near Barriers* — Roads or other discontinuities between geographic units that are never (for barriers) or rarely (for near barriers) crossed by target species. Barriers effectively isolate target species populations on adjacent habitat units from one another, while near barriers may separate subpopulations into a "metapopulation" system, with individuals occasionally dispersing between subpopulations in different units. For wide-ranging species like bobcats or mountain lions, barriers or near barriers may define one boundary of a home range, as individuals recognize it as the edge of available habitat. Major freeways and associated physical features (e.g., embankments, drainage improvements, retaining walls, lane dividers, fences, wide areas devoid of vegetation) create impassible barriers for nearly all ground-dwelling species, unless sufficient crossing structures (e.g., bridges, culverts, vegetated over-crossings) facilitate movements (Beier et al. in press, Evink 2002, Haas 2002, Lyren 2001). For example, the concentration of roads and commercial developments associated with Interstate 605, separating Whittier Hills from Whittier Narrows, represents a barrier for most or all target species. Near barriers are similar, but they may have one or more crossing structures that can be used by at least some target species; or target species may occasionally cross at-grade, on the road surface (perhaps at high risk of roadkill). Highway 57 and Harbor Boulevard are examples of near barriers in the study area. Both have high traffic volumes and physical characteristics that discourage crossings, except at one excellent bridge crossing at Tonner Canyon (for Highway 57) and one stretch where wildlife cross Harbor Boulevard at-grade—albeit with frequent roadkill.

- *Filter (Permeable and Highly Permeable)* — Filters are discontinuities in habitat connectivity that are readily to moderately crossable by most but not all target species. For example, two-lane paved roads with low traffic volumes and little associated development are readily crossed by larger mammals (although there may be occasional roadkill); but other species, like horned lizards, may be reluctant to cross or may suffer high roadkill. Thus, such roads serve to "filter" some species out of the community of wildlife crossing between adjoining habitat units. Several permeable to highly permeable roads cross the study area, such as Turnbull Canyon Road through the Whittier Hills (between Segments 6 and 7). The larger mammals, roadrunners, and some reptiles probably cross this road at-grade with little hesitation, and individual home ranges may straddle it. However, some smaller or more sedentary species may have their populations segmented by this road into subpopulations, with only occasional cross-road dispersal.

## Analyses — Assessing Existing and Future Functionality

For each target species, I followed the following analytical steps:

1. I assigned each of the nine geographic segments to one of the functional categories (core, subcore, patch) as if each functioned independently of the others (i.e., as if roads separating the units acted as barriers or near barriers to dispersal). This initial categorization was based exclusively on unit size. For example, any unit less than 60 sq. km would be considered a patch if it functioned independently of other units in supporting a target species.

2. I assessed each road separating the units to determine whether it acted as a barrier (or near barrier) or filter (permeable to highly permeable). If a road was not considered a barrier/near barrier for a target species, and the two units it separated appeared to function as one larger unit for that species, the area of the two units was summed and the function of the new composite unit was reassessed. For example, if the composite unit exceeded 60 sq. km, it was considered to function as a subcore rather than two separate patches.

3. Based on this revised, species-specific functionality assessment, I assigned each newly defined unit (or composite unit) a function relative to supporting individuals or populations of each target species based on unit size, habitat composition, and other factors gleaned from the literature and field reconnaissance. These species-specific functions were defined as follows:

   - *Population* — capable of supporting a breeding population of at least 20 adults and potentially serving as a source of individuals that disperse into other units.

   - *Subpopulation* — capable of supporting at least two but less than 20 breeding individuals. Not likely to be a reliable source population, but may exchange individuals with other areas within a larger metapopulation (a set of partially isolated populations linked by occasional dispersal) and may provide individuals to recolonize habitat patches in case of local extirpation.

- *Home Range Part* — incapable of supporting at least two breeding individuals on its own, but may provide live-in habitat (e.g., foraging or resting cover) and form a part of one or more individuals' home range(s).
- *Move-through* — not contributing significant live-in habitat for a species as part of a functional home range, but capable of accommodating movements between more substantial units within a home range, or potentially used for dispersal between other habitat units.

4. This classification system was used to assess likely effects of future scenarios on wildlife populations or movements, such as (a) adding new roads or development that would introduce new barriers or reduce the size of a functional unit, or (b) adding or improving wildlife crossing structures that would allow two independent units to serve as one larger one.

# Results

## *Functionality of Geographic Units*

Table 2 summarizes characteristics of the geographic units, including their size, vegetation composition, known or inferred presence/absence of target species, initial functional classification (core, subcore, patch), and reserve status (conserved/unconserved). Only the Santa Ana Mountains unit met the definition of a core area (larger than 2,000 sq. km and capable of supporting a mountain lion population). The Chino Hills between Highways 91 and 142 met the definition of a subcore (60-2,000 sq. km and capable of supporting a population of bobcats). Six other segments of the Puente-Chino Hills Wildlife Corridor met the definition of patch, but with great variation in their capacity to support wildlife and wildlife movements. The disjunct Whittier Narrows met the definition of an isolate.

Table 3 summarizes pertinent characteristics of the major roads dividing these units, with a focus on their role as barriers or filters to wildlife movement. Following below is a more detailed, unit-by-unit review of the information, concerning how each unit appears to function in supporting wildlife populations and movements, considering the effects of intervening roads and other factors. This review starts with the Santa Ana Mountains Core Area, then describes the seven segments of the functional Puente-Chino Hills Wildlife Corridor, and ends with the isolated Whittier Narrows.

*Santa Ana Mountains (Core)*

At about 2,070 sq. km, wildlands in the Santa Ana Mountains comprise the only true core in the study area. They support a high diversity of wildlife in a relatively intact and healthy representation of Southern California's South Coast ecosystem (Spencer et al. 2001), including substantial populations of all the target species. Noss et al. (1997) estimated populations of breeding adults in the Santa Ana Mountains at about 4,000 mule deer, 15-20 mountain lions, up to 500 bobcats, and more than 500 coyotes. These populations are large enough to persist, at least in the short term, within the Santa Anas without immigration from other habitat areas—although at least the mountain lion needs occasional immigration from adjacent mountain ranges to persist in the long term (Noss et al. 1997, Beier 1993). Of course, all species and ecosystem functions benefit from connectivity to other wildlands. The breeding population of about 15-20 mountain lions serves as a source of lions moving into the Puente-Chino Hills via the Coal Canyon Underpass (Beier 1995, Noss et al. 1997).

The Santa Ana core area is separated from the Chino Hills by busy Highway 91 and associated developments. However, the Coal Canyon Wildlife Underpass was restored specifically to mitigate this strong barrier to movements and appears to be functional (Figure 2).

**Table 2.** Characteristics of geographic units comprising the Puente-Chino Hills Wildlife Corridor (from east to west).

| | | **Segments of the Functional Puente-Chino Hills Wildlife Corridor** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Santa Ana Mountains** | **Chino** | **Carbon-Tonner** | **Shell-Aera** | **Powder-Schabarum** | **San Miguel** | **E. Whittier** | **W. Whittier** | **Whittier Narrows** |
| Segment Number | N/A | 1 | 2 | 3 | 4 | 5 | 6 | 7 | N/A |
| Size (sq. km.) | ~2,070 | 85.6 | 44.3 | 13.3 | 5.7 | 1.5 | 5.2 | 7.1 | ~4.5 |
| Vegetation Mosaic | | | | | | | | | |
| Shrubland | | 51.3% | 51.9% | 45.2% | 48.9% | 57.1% | 43.4% | 67.0% | |
| Grassland | N/A | 36.5% | 29.4% | 37.7% | 21.0% | 31.8% | 36.1% | 17.1% | N/A |
| Woodland | | 12.1% | 18.7% | 17.2% | 30.1% | 11.4% | 20.4% | 15.9% | |
| Wetland | | 0.1% | 0.1% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | |
| Spp. Presence/Absence* | | | | | | | | | |
| Mountain lion | P | P | P | P? | P? | P? | P | P | A? |
| Bobcat | P | P | P | P | P | P | P | P | A? |
| Coyote | P | P | P | P | P | P | P | P | P? |
| Mule deer | P | P | P | P | P | P | P | P | ? |
| Roadrunner | P | P | P | P | P? | P? | P | P | ? |
| Coast horned lizard | P | P | P | A? | A? | A? | A? | A? | A? |
| Biological Function | core | subcore | large patch | patch | patch | small patch | patch | patch | isolate |
| Reserve Status | substantially conserved | substantially conserved | Carbon Cyn partly conserved, Tonner Cyn unprotected & threatened | unprotected & threatened | partly conserved, partly threatened | partly conserved, partly threatened | substantially conserved | substantially conserved | substantially conserved |

*See Table 1 for supporting literature. P = confirmed present; A = likely absent; ? = presence or absence inferred by indirect evidence and geographic context, but no confirmatory data found.

**Table 3.** Characteristics of roads crossing the Puente-Chino Hills Wildlife Corridor.

| **Road** | **Geographic Units Separated** | **Critical Crossing Structures*** | **Characteristics** | **Effect on Movements** |
|---|---|---|---|---|
| SR 91 | Santa Ana/Chino | Coal Canyon Wildlife Underpass | Major, 6-lane freeway with heavy traffic and significant physical barriers to wildlife. | Barrier, except for Coal Canyon Underpass |
| Carbon Canyon Rd. (SR 142) | Chino/Carbon-Tonner | Square box culvert near Chino State Park entrance. | Busy 2-lane highway through mostly wild open space. Moderate-high coyote roadkill. Few physical barriers. | Permeable filter, with some roadkill (esp. coyote). Mix of at-grade crossings and culverts, at least one used by bobcat. |
| SR 57 | Carbon-Tonner/Shell-Aera | Tonner Canyon Bridge | Major 6-lane freeway with heavy traffic and significant physical barriers to wildlife. | Barrier except for Tonner Canyon Bridge, with documented use by deer, bobcat, and coyote. |
| Harbor Blvd. | Shell-Aera/Powder-Schabarum | Harbor Blvd. Wildlife Tunnel (proposed) | Major 4-lane arterial with heavy traffic and significant barriers to wildlife. High roadkill. | Barrier, except for occasional at-grade crossing, with very high roadkill. |
| Hacienda Blvd. | Powder-Schabarum/San Miguel | none (except a little-used equestrian tunnel that could be improved) | Busy 2-lane road with steep slopes and cut banks, but several at-grade crossing areas. | Filter, with moderate roadkill risk. |
| Colima Rd. | San Miguel/East Whittier | Colima Service Tunnel | Busy 4-lane road with physical barriers, including fences that may help funnel wildlife to undercrossing. | Filter, with relatively low roadkill due to fences and a well-used undercrossing with known use by deer, bobcat, and coyote. |
| Turnbull Canyon Rd. | East Whittier/West Whittier | none | Winding, 2-lane road with light traffic through wild habitat. | Highly permeable filter, with at-grade crossings in wild open space. |
| Interstate 15 & Workman Rd. | West Whittier/Whittier Narrows | none | Major 6-lane freeway with heavy traffic, plus other major and minor roads, commercial development, and other physical barriers to wildlife. | Barrier to essentially all ground-dwelling species. |

*Includes only those structures used by diverse target species and especially larger mammals. Numerous smaller culverts that may serve some target species also occur, as do some larger equestrian tunnels that are in landscape positions not favoring use by target species. See Haas (2000) and Robertson et al. (1995) for a more comprehensive review of crossing structures in the study area.

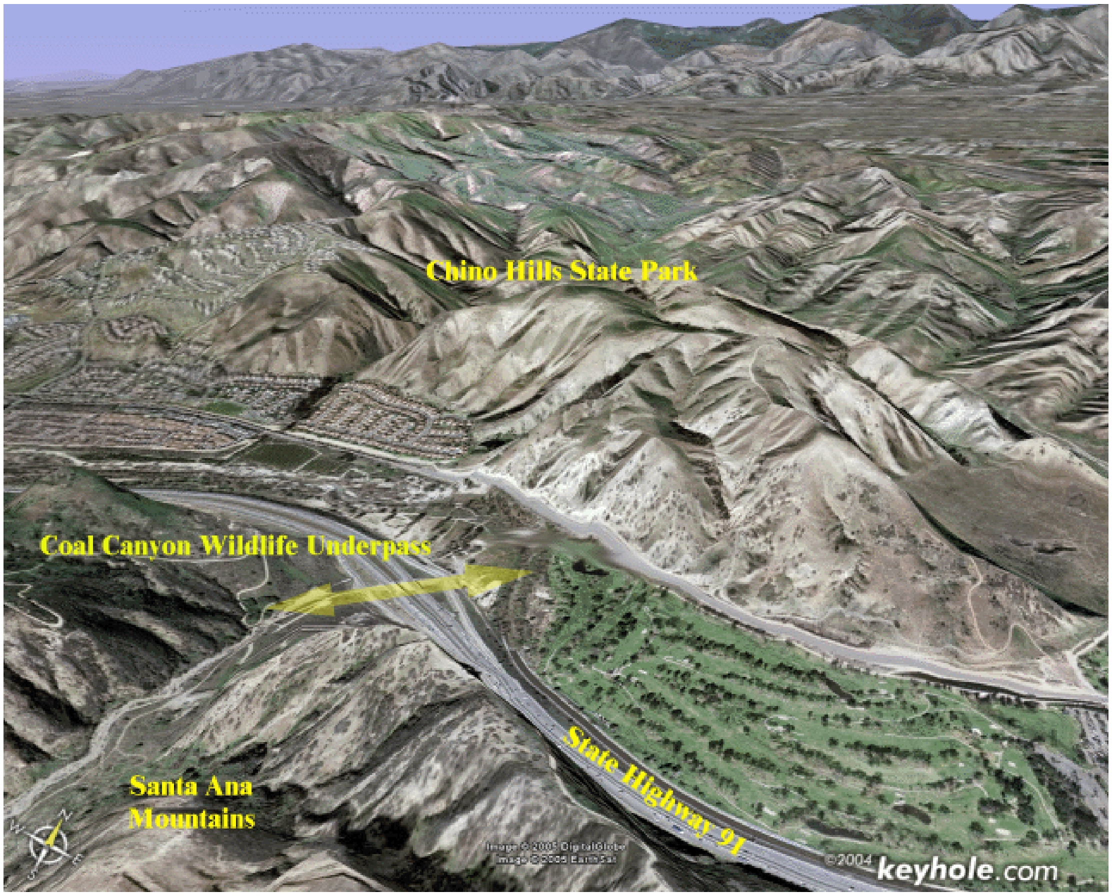



**Figure 2.** View northwest across Coal Canyon Wildlife Underpass, which links wildlife movement between the Santa Ana Mountains and Chino Hills State Park (Keyhole screenshot).

*Corridor Segment 1—Chino*

At over 85 sq. km, the Chino Hills represent a substantial subcore supporting diverse and relatively healthy ecological communities. It supports one to a few mountain lions, forming at least a portion of their home ranges, due to its connection to the Santa Ana Mountains population via the Coal Canyon Wildlife Underpass. Segment 1 also supports significant populations of all other target species (Lyren 2001, Cooper 2000, Haas and Crooks 1999, Haas 2000, Noss et al. 1997) and has higher overall biological diversity than other segments. For example, of all the segments they sampled for reptiles and amphibians in the Puente-Chino Hills Wildlife Corridor, Haas et al. (2002) reported the highest richness of herpetofauna (22 species captured) in the Chino Hills. They further reported the highest levels of species diversity (using a variety of diversity indices) and evenness (an index of relative abundance across all species) in the Chino Hills, with a general decline in these measures as one moves west through the corridor. Moreover, the number of sensitive amphibian and reptile species recorded by the study dropped from 7 in the Chino Hills to 4 in the Whittier Hills. No western spadefoot toads (*Spea hammondii*), western pond turtles (*Clemmys marmorata*), coast horned lizards, or coast patch-nosed snakes (*Salvadora hexalepis*) were found west of the Chino Hills. These results undoubtedly reflect the larger size of Segment 1 (and adjoining Segment 2) compared with other segments, its proximity to the Santa Ana Mountains Core, and the increasing number of barriers and filters encountered moving west from this source area through the corridor. Similar patterns in diversity, abundance, and evenness measures would be expected for other taxa (e.g., birds, small mammals, insects, plants) if comparable data were available to document them.

Segment 1 is largely conserved already as Chino Hills State Park, although efforts continue to increase the size and buffering of this important reserve area. It is separated from Segment 2 by Carbon Canyon Road (Highway 142). This busy 2-lane road suffers some roadkill, especially coyote (Robertson et al. 1995), but is generally quite permeable to target species due to extensive, naturally vegetated land on both sides, lack of development over much of its length, and availability of several undercrossings. The most significant undercrossing is a 1.4-m (4.5-ft) high square box culvert used by bobcats and other target species (Robertson et al. 1995). This road is therefore classed as a permeable filter, allowing Segments 1 and 2 to function as one larger subcore for most species and ecological processes. Notably, Haas et al. (2002) and Case and Fisher (1998) recorded coast horned lizards on both sides of Carbon Canyon Road, but not farther west along the corridor.[5]

*Corridor Segment 2—Carbon-Tonner*

This large (44.3 sq. km) patch appears to function more as an extension of the Chino Hills subcore, being separated only by permeable Carbon Canyon Road (see previous). It is biologically diverse and supports all target species, including the westernmost observations of horned lizards by Haas et al. (2002) and Case and Fisher (1998). The southern portion of Segment 2 (including lower Carbon and Tonner Canyons and associated ridges) has been identified as a conservation priority for birds due to its support of several regionally rare or declining species, including greater roadrunners, loggerhead shrike, cactus wren, California gnatcatcher, grasshopper sparrow, and sage sparrow, among others (Cooper 2000). The northern portion of the segment (upper Tonner Canyon) is also rated as a conservation priority for birds, including golden eagle, burrowing owl, northern harrier, cactus wren, tricolored blackbird, and grasshopper sparrow, among others (Cooper 2000). Tonner Canyon also supports significant California walnut woodlands.

The eastern half of Segment 2 contains the western slopes and ridges of the Carbon Canyon landscape and is partially conserved as part of Chino Hills State Park and the Firestone Scout Reservation. The western half of this segment, containing most of Tonner Canyon, is unconserved and threatened by several proposed developments. Tonner Canyon is almost entirely owned by the City of Industry, which proposes a new road along the east side of Tonner Canyon (Map 2) and new water reservoirs within the canyon. This threatened half of the segment comprises the eastern portion of the Missing Middle.

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[5] During my literature review, I found no recent confirmed records for coast horned lizards farther west than a ridge between Carbon and Tonner Canyons near Olinda Landfill (Haas et al. 2002). However, one table in a draft report (LSA 2005) listed the species as "observed" in the Whittier Hills, although another table in the same reference indicated the horned lizard as potentially present but not observed there.

The Olinda Landfill occupies a large footprint in the south-central part of Segment 2, between Tonner and Carbon Canyons. The landfill eventually will be closed and restored to natural vegetation as a County regional park, adding to the area of conserved open space here (C. Schlotterbeck, personal communication).

Segment 2 is divided from Segment 3 by busy Highway 57. This freeway is a near total barrier to ground-dwelling wildlife, except for one high-quality underpass in lower Tonner Canyon (Figure 3 and Photo 1). This bridge over Tonner Creek is very wide and open, with sufficient natural cover to facilitate movement by all target species. The bridge is used by mule deer, bobcat, coyote, and numerous other species (PCR 2002, Haas 2000, Haas and Crooks 1999, Robertson et al. 1999, personal observations). Maintaining this function is widely considered critical to maintaining the functional Puente-Chino Hills Wildlife Corridor, but it is threatened by the City of Industry plan for a new road originating here and traveling up Tonner Canyon to Diamond Bar.

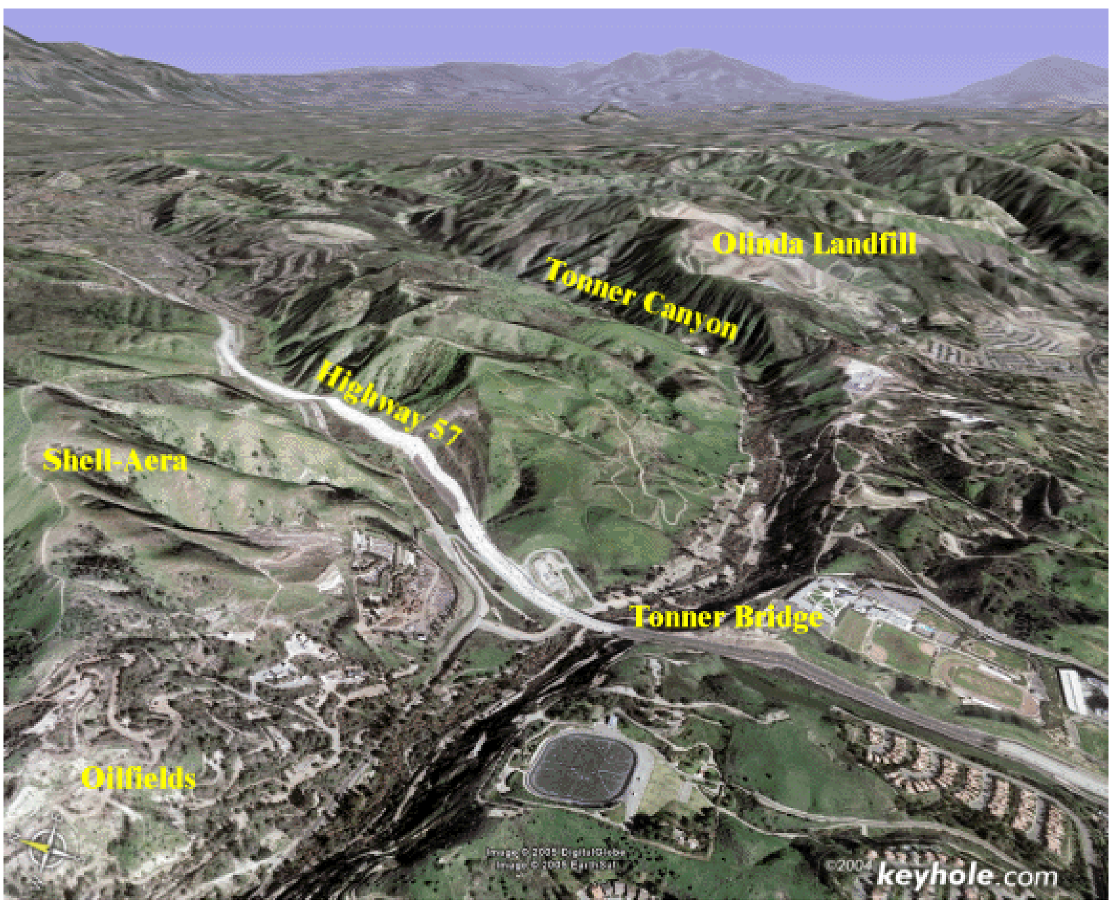



**Figure 3**. View northeast across Tonner Bridge and Highway 57 (Keyhole screenshot). Wildlife on both sides of Highway 57 (a barrier road) are funneled to cross under Tonner Bridge.

**Photo 1.** View east under the Tonner Bridge, the only functional crossing beneath Highway 57 for deer, mountain lion, bobcat, and other wildlife species.

*Corridor Segment 3—Shell-Aera*

This segment, between Highway 57 and Harbor Boulevard, comprises the western portion of the Missing Middle. It is named for the Shell-Aera Master Planned Community property (2,935 acres or 11.9 sq. km), which comprises 90% of the segment's remaining undeveloped land and is proposed for development. In addition to the Shell-Aera property, Segment 3 includes some privately owned open space lands conserved as mitigation for previous developments in the vicinity, such as the Shea homes development off of Harbor Boulevard in the northwest portion of the segment.

Although smaller than Segments 1 and 2, and bounded by two near-barrier roads, this substantial habitat block (13.3 sq. km) supports diverse vegetation and wildlife communities and is generally recognized as essential to maintaining connectivity through the Puente-Chino Hills Wildlife Corridor (PCR 2002, PCR 2000, Haas 2000, Robertson et al. 1995, personal observations). Cooper (2000) recognized the area as being of high conservation concern for its support of rare or declining bird species, including greater roadrunner, golden eagle, and grasshopper sparrow, among others. The Shell-Aera property was not open to sampling by most studies included in this analysis. However, PCR (2002) performed biological surveys on the property and confirmed presence and movements of all target species except mountain lion and horned lizard. Although horned lizards are likely extirpated here, mountain lions undoubtedly do use the property—probably both as move-through habitat and as foraging habitat. There is essentially no other way for lions to make it to segments farther west, where lion presence has been confirmed (A. Henderson, A. Gullo, and C. Schlotterbeck, personal communications), from the source populations to the east. The segment also supports deer and other prey species and appears to have suitable cover, despite a history of grazing that has degraded woodland and shrubland habitats. The Shell-Aera property also supports some of the best remaining examples of California walnut woodland in Southern California (approximately 16,000 walnut trees covering 475 acres), although regeneration has been hampered by grazing (Quinn 1998, in PCR 2002).

Harbor Boulevard, which forms the western boundary of Segment 3, is a formidable barrier to target species movement. It is wide, with fast and heavy traffic, and currently lacks any underpasses. A combination of natural and man-altered topography tends to funnel wildlife to a stretch of road just south of the Shea Homes development, where a steep-sided riparian drainage ("Drainage 26") abuts a steep fill slope below the road, adjacent to housing (Figure 4). A variety of wildlife trails converge here, and several cross the road and continue northwest along a powerline right-of-way into Powder Canyon. Signs of target species usage (bobcat, deer, coyote) are especially abundant in Drainage 26, and roadkill frequency is very high in this stretch of road, especially for coyote (PCR 2002, Robertson et al. 1995, personal observations). Figure 4 illustrates major movement concentrations on the Shell-Aera property as they relate to this problem road-crossing area. Photo 2 shows a road-killed coyote I observed on March 2, 2005,

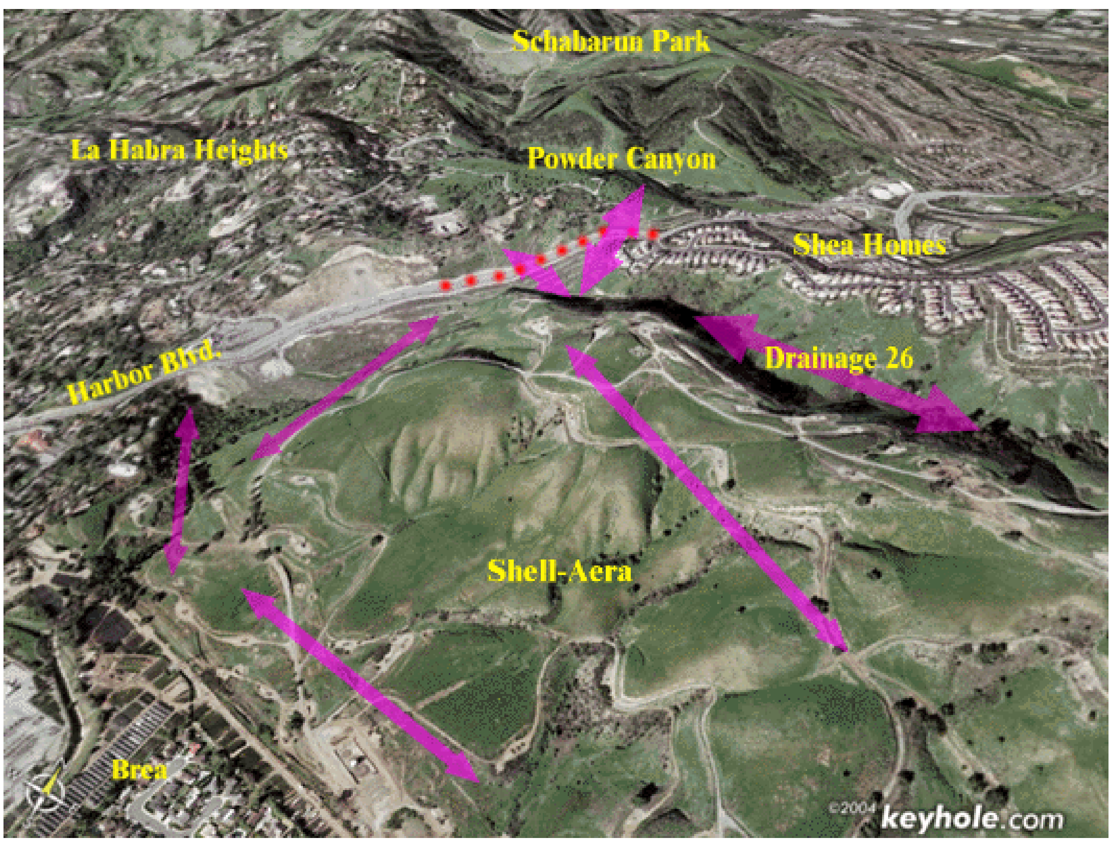



**Figure 4.** View northwest across Segment 3 and Harbor Boulevard to Segment 4, indicating general trends in wildlife movements (Keyhole screenshot). Arrow widths indicate inferred relative use levels. Red dots indicate stretch of highest roadkill.

where Harbor Boulevard crosses the Shea Homes development after Drainage 26. I surmised that this coyote entered the roadway out of Drainage 26 via one of several clear wildlife trails. Fortunately, recognition of this problem road-crossing has resulted in approval of a wildlife underpass here, although fencing to direct wildlife to the tunnel, considered essential to its success, has not been approved on the Shell-Aera property (A. Henderson, personal communication).


**Photo 2.** View southeast across the Harbor Boulevard "deathtrap." Drainage 26 extends out of view to the left from the bend in Harbor Boulevard. Note road-killed coyote and heavy traffic.

*Corridor Segment 4—Powder-Schabarum*

This segment (about 5.7 sq. km) is relatively small but nevertheless significant, especially as a link between larger habitat units to the east and west. Deer, bobcat, and coyote are commonly seen moving through the segment (Robertson et al. 1995). Haas (2000) recorded a lower frequency of bobcat visitations to track stations in this segment (and adjoining Segment 5) than in larger segments in the study area, which he attributed to the narrowness of this stretch of the wildlife corridor and consequently greater edge effects and disturbance factors.

Powder Canyon open space makes up the southern portion of Segment 4, and Schabarum Regional Park makes up the northern portion. The segment averages about 1.5 km wide over most of its length, but narrows to about 0.5 km in the western portion approaching Hacienda Boulevard. Wildlife movement becomes quite constrained in this narrow portion by existing housing, fences, and other impediments. Hacienda Boulevard separates this constrained portion of Segment 4 from Segment 5. Although Hacienda Boulevard has lower traffic volumes and speeds than the highways discussed above, it has very steep slopes and cuts, with no reliably used crossing structures. An existing equestrian tunnel, that is infrequently used by target species, could be improved with fencing and revegetation (Haas 2000 and personal observations). Hacienda Boulevard has several at-grade crossing concentrations and trails (Haas 2000, Robertson et al. 1995, personal observations), which are probably associated with moderate roadkill. I rated this as a permeable filter, as it is crossable by most target species; however, it may act as a strong filter due to these and other constraints, and it represents a bottleneck to movement in need of improvement (Haas 2000).

*Corridor Segment 5—San Miguel*

This is the smallest (1.5 sq. km) segment of the entire corridor system. Along with the narrow constriction in the west end of Segment 4, this segment represents the narrowest habitat constriction along the wildlife corridor system (0.5 to 1.0 km wide). It is also perhaps the most disturbed by humans and their pets, particularly on northern slopes (Haas 2000, Robertson et al. 1995). Haas recorded low use by target species (no bobcat use) on the northern portions of this segment, along the Skyline Trail, but high levels of cats, dogs, striped skunks, and raccoons. The abundance of these mesopredators that are adapted to human environments often reflects low presence of coyotes and other large predators, which suppress these species when present (Crooks and Soulé 1999), as well as higher human influences and edge effects. Haas (2000) recorded bobcat activity in the southern portion of the segment, in association with less disturbed areas of San Miguel Canyon and near Skyline Drive. He noted that the transects with the greatest bobcat activity were also those with the lowest dog activity. Haas surmised (as did Robertson et al. 1995) that large mammals travel along Skyline Drive and descend into San Miguel Canyon towards the Colima Service Tunnel (discussed below). Low density housing in this segment, especially near Hacienda Boulevard, may reduce habitat quality for target species, but does not present barriers to movement (Haas 2000, Robertson et al. 1995). For some target species, Segment 5 may function primarily as move-through habitat, although a few coyotes and bobcats probably forage in San Miguel Canyon.

Segments 5 and 6 are divided by Colima Road, a fairly busy 4-lane road winding through a mix of open space and scattered housing. Although flanked by steep slopes, some fences, and other movement impediments, there are several at-grade crossing areas, which are associated with high coyote roadkill (Haas 2000, Robertson et al. 1995). One good under-crossing structure exists at a service tunnel near the southern edge of the habitat area (Colima Service Tunnel). Bobcats, coyotes, and deer use this tunnel (Robertson et al. 1995, Haas 2000, Haas and Turschak 2002), and they continued using it even after a dramatic increase in recreational uses of the tunnel and vicinity by humans and dogs during 2001-2002 (Haas and Turschak 2002). Most wildlife species use the tunnel between sunset and sunrise, whereas human and dog use occurs almost exclusively during daylight (Haas and Turschak 2002). Conserving and improving this tunnel for continued wildlife use, especially at night, is a conservation priority.

*Corridor Segments 6 and 7—East Whittier and West Whittier*

The wildlife corridor widens again in the Whittier Hills from the narrow and constrained Segments 4 and 5. Segments 6 and 7 are separated by Turnbull Canyon Road, which appears to be the most permeable road analyzed in the study area. It is a narrow, 2-lane road with relatively light traffic, winding through fairly undisturbed wildlands. Haas (2000) recorded no roadkills here and did not consider Turnbull Canyon Road a barrier or major hazard to mammals. Likewise, Robertson et al. (1995) did not consider Turnbull Canyon Road a significant impediment to movement, which corresponds with my field observations. Consequently, Segments 6 and 7 are discussed here together as one continuous geographic unit (Whittier Hills).

The Whittier Hills support significant biological values despite their location at the terminus of the range of connected wildlands, far from the Santa Ana Mountains Core. This area had the highest levels of deer and bobcat activity recorded by Haas (2000), and higher species richness of reptiles and amphibians than narrower segments farther east (Haas et al. 2002). Mountain lion presence has recently been confirmed in the area by several lion-predated goats and deer, and at least one likely lion scat (Haas 2000; A. Henderson, C. Schlotterbeck, and A. Gullo, personal communications).

However, monitoring results also show that the Whittier Hills have lost some species and may be close to losing more due to their distance from core areas and numerous intervening barriers and filters to movement. For example, despite the relatively high total number of reptile and amphibian species they recorded here, Haas et al. (2002) also found the Whittier Hills to have the lowest overall *evenness* in the study area (Haas et al. 2002). This evenness finding means that the local herpetofauna consists of a few abundant species plus many less abundant species, in contrast to the Chino Hills, where high evenness indicated healthy populations of most species. Those species detected in low numbers in the Whittier Hills may represent remnants of dwindling populations, possibly on their way to extirpation with little hope of being "rescued" by new colonists from other areas (Brown and Kodric-Brown 1977) due to the great distances and numerous barriers involved. Moreover, the Whittier Hills support fewer sensitive species of reptiles and amphibians than the Chino Hills, as various species drop out in an apparent east-west gradient from the Chino Hills through the wildlife corridor to the Whittier Hills (Case and Fisher 1998, Haas et al. 2002).

The Whittier Hills are separated from the Whittier Narrows by an array of formidable barriers, including Workman Road, Interstate 605, and a wide, unbroken surface of buildings and pavement. Together, these create a near total barrier to movement for all target species.

*Whittier Narrows (Isolate)*

Because it is functionally isolated from the Puente-Chino Hills Wildlife Corridor, I did not investigate this area in detail. Although this matrix of wetland and disturbed upland habitats probably supports some coyotes (a semi-isolated subpopulation?), it is unlikely to support other target species in perpetuity.

## *Summary of Overall Corridor Function*

In general, the Puente-Chino Hills Wildlife Corridor appears to be functional for at least larger mammals and birds, although tenuously so in the Missing Middle (due to several barrier roads and near barrier roads) and across smaller Segments 4 and 5 just west of the Missing Middle (due to their small size, strong edge effects, and high human and dog activity). Essentially all roads in the study area are considered barriers or at least strong filters to movements by many reptiles, amphibians, and small mammals, although most birds and larger mammals currently can move between all segments either at-grade (with mortality risks) or via critical crossing structures. Despite constraints in many locations along the corridor, target species are confirmed or highly likely to occur in all seven corridor segments, except for the coast horned lizard, which may already be absent, or will disappear in the future, west of Highway 57.

Mountain lions are capable of traversing the length of the corridor, albeit at some risk of roadkill, and one or more lions still hunt as far west as the Whittier Hills. Most other target species probably persist over the length of the corridor as metapopulations, with subpopulations segregated among geographic units by the presence of barrier or near barrier roads. These subpopulations may be linked demographically and genetically by occasional dispersal, or by within-home range movements of some individuals, depending on each species' ability to navigate roads and crossing structures. For example, bobcats apparently have small subpopulations living in the Whittier Hills and within Segment 3 (Shell-Aera), and a larger source population living within the Chino Hills (Segments 1 and 2). Some individual bobcats probably have home ranges completely or partially within smaller segments (e.g., 4 and 5) between these more substantial habitat areas; or they occasionally move through the smaller segments, between larger ones, and thus keep the overall metapopulation interconnected demographically and genetically. This metapopulation persistence depends on both occasional cross-road movements (i.e., functional road-crossings) and sufficient patch size and habitat quality to sustain small subpopulations within segments.

Haas et al. (2002) described a gradient of declining diversity and evenness of reptile and amphibian species, moving west from the Chino Hills. This must be attributed to higher mortality and edge effects in the more fragmented portions of the study area, exacerbated by the greater distance and increasing number of barriers and filters that must be crossed as one moves farther west from source populations. This pattern of decreasing biological diversity in the western portions of the corridor is likely to be mirrored by other taxa that respond similarly to distance and barrier effects, such as small mammals. In terms of metapopulation dynamics, if a local population or subpopulation dwindles or disappears from one segment (e.g., Whittier Hills), it is less likely to be "rescued" by colonists from other segments (e.g., Chino Hills) the farther away it is from the source population and the greater the number of intervening barriers and filters. Hence, the farther west a segment lies, the greater the likelihood of local population declines or extirpations, at least for less mobile species (Haas et al. 2002).

Table 4 summarizes the conclusions from the preceding review of geographic units and roads and presents a conceptual model of how each geographic unit (or composites of adjoining units lacking barriers) appears to function in supporting populations of target species within this segregated landscape. This table integrates diverse information, including published estimates of home ranges and densities of target species in Southern California, results of the monitoring studies summarized in Table 1, variation in habitat quality and mortality factors throughout the study area, and professional judgment. The carrying capacity estimates (in parentheses for some species) are rough approximations only, intended as order-of-magnitude estimates of the capacity of each geographic unit to support populations or subpopulations of target species, or to function as part of one or more home ranges, or to function as pass-through habitat between other units.

Where adjoining segments are considered to function as one unit for a particular target species (e.g., if individuals readily cross roads and populations are not considered segmented by them), the area of those segments is summed. Thus, Segments 1 and 2 are combined to form new Segment 1/2 (Chino-Tonner), because Carbon Canyon Road is quite permeable for most species. Likewise, Segments 6 and 7 (the Whittier Hills) appear to serve as one contiguous geographic unit for nearly all target species, except the horned lizard, which is likely absent.

Vertical lines separating adjacent segments in Table 4 represent roads considered to segment populations for a given species. However, note that even where barrier roads do not prevent movement between adjoining segments, those segments may be treated separately in the table's classification of segment function for a target species. For example, although the roads bounding Segment 5 are not considered mountain lion barriers, Segment 5 is rated separately as "pass-through habitat" for lions (due to small size and edge constraints), whereas Segment 4 and combined Segments 6/7 are considered foraging habitat and therefore parts of a functional home range for one or two lions that pass through Segment 5 to reach them. Similarly, although Colima Road is not a strong barrier to movement for bobcats, coyotes, or deer, narrow and edge-effected Segments 4 and 5 likely support, at most, small subpopulations (a few resident individuals) or portions of a few individual home ranges for these species, whereas the larger and more contiguous Whittier Hills unit can support more robust and sustainable subpopulations.

By reading across the rows of Table 4 for any species, one can envision how the presence of species is maintained throughout the corridor via individual movements and metapopulation dynamics, with each segment (or combination of segments) serving as stepping stones along the way (either for an individual of a wide-ranging species like mountain lion—which may traverse the entire corridor—or over several generations for smaller species, whose individuals may move over only one or a few segments in a lifetime). For example, the only source population for mountain lions is the Santa Ana Mountains Core. The one to three resident lions that use the combined Chino-Tonner unit would not be there without this core population or the Coal Canyon Wildlife Underpass (Beier 1993, Noss et al. 1997, Haas 2000). One or more of these resident lions at least occasionally use Segment 3 (Shell-Aera) as foraging or pass-through habitat as a portion of their home range (made possible by the Tonner Bridge between Segments 2 and 3). From there, one or more lions occasionally forage in or move through Powder Canyon (Segment 4) and San Miguel Canyon (Segment 5) to forage in the Whittier Hills (combined Segments 6/7).

**Table 4.** Functional classification of geographic units for supporting target species populations and movements, considering effects of inter-unit barriers and filters, road-crossing structures, habitat quality, and other factors. Vertical lines indicate presence of barriers or near barriers between units for that species (names supplied for major roads). Classifications spanning multiple unit columns indicate those units are assumed to function as one for that species, using the summed size of units. Carrying capacity (numbers in parentheses) are crude estimates only, based on results of monitoring studies (see Table 1), published home range sizes and densities, habitat mosaics in each segment, and professional judgment. They are intended as order-of-magnitude estimates for the purpose of assigning functional classes, and not as precise population estimates.

| | | | **Segments of the Functional Puente-Chino Hills Wildlife Corridor** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | **1/2–Chino-Tonner** | | | | | | | | **6/7–Whittier Hills** | | | |
| | **Santa Ana Mtns Core Area** | | **1-Chino** | **2-Carbon-Tonner** | | **3-Shell-Aera** | | **4-Powder-Schabarum** | **5-San Miguel** | | **6-E. Whittier** | **7-W. Whittier** | | **Whittier Narrows (Isolate)** |
| **Unit Size (sq. km)** | ~2,070 | | 85.6 | 44.3 | | | | 5.7 | 1.5 | | 5.2 | 7.1 | | ~4.5 |
| **Summed Size** | | | 129.9 | | | 13.3 | | 7.2 | | | 12.3 | | | |
| **<u>Target Species</u>** | | | | | | | | | | | | | | |
| **Mountain lion** | Pop (15-20) | **SR 91** | Subpop (1-3) | | **SR 57** | HR Part (1-2) | **Harbor Blvd** | HR Part (1-2) | Pass-thru | **Colima Rd** | HR Part (1-2) | | **I- 605** | Absent |
| **Bobcat** | Pop (100-400) | | Pop (20-50) | | | Subpop (2-10) | | Subpop/HR Part (2-5) | | | Subpop (5-15) | | | Absent? |
| **Coyote** | Pop (200-500) | | Pop (20-50) | | | Subpop (5-12) | | Subpop/HR Part (2-7) | | | Subpop (15-25) | | | Subpop? |
| **Mule deer** | Pop (2,000-4,000) | | Pop (100-300) | | | Subpop (10-25?) | | Subpop/HR Part (5-15) | | | Subpop (15-30) | | | Absent? |
| **Roadrunner** | Pop (hundreds) | | Pop (20-100) | | | Subpop (?) | | Subpop (?) | HR Part (?) | | Pop(?) | | | Absent? |
| **Coast horned lizard** | Pop (thousands) | | Pop (hundreds?) | Pop (hundreds?) | | Absent? | | Absent? | Absent? | | Absent? | Absent? | | Absent? |

Pop = capable of supporting a breeding population of ≥20 individuals and potentially serving as a source population via dispersal to other segments.

Subpop = capable of supporting 2-19 individuals as part of a metapopulation connected by at least occasional dispersal between other segments.

HR Part = could comprise part of one or more individual home ranges in concert with adjoining areas, but by itself is unlikely to support a breeding pair.

Pass-thru = used for movement between adjoining units, but unlikely to support individual life requisites (foraging, breeding, etc.) or a home range.

If any of the critical road crossings becomes non-functional, lions would no longer use more westerly segments, because no segments are capable of supporting a population of lions in isolation (other than the Santa Ana Mountains Core). Moreover, if any segment is reduced in size or quality to become only move-through habitat (rather than live-in habitat), the probability of lions using this unit, or any units lying further west, would drop considerably. Hence, maintaining lions in the Whittier Hills ecosystem depends not only on maintaining the possibility of unimpeded movement by individuals along the corridor, but also on maintaining substantial live-in habitat along the way.

Similarly, subpopulations in the Whittier Hills of bobcats, mule deer, roadrunners, and, to a lesser extent, coyotes exist in part due to other population or subpopulation segments (i.e., source habitats) along the corridor. Thus, the substantial habitat blocks in Segments 2 and 3 are important to continued presence of target species many kilometers away in the Whittier Hills. Substantial reduction in the carrying capacity of any one segment increases the probability of species losses in other segments. Thus, for example, the large area of Segment 3 (Shell-Aera) is a major potential contributor to the continued presence of bobcats, mule deer, mountain lions, roadrunners, and many other species in the Whittier Hills, especially if habitat quality is increased and road crossings are improved.

To summarize, the ability of westerly segments of the corridor to support species depends both on (1) the potential for individual movement between each set of adjoining segments (a function of roads and road crossings), and (2) having sufficient live-in habitat along the way to support populations or subpopulations that contribute dispersing individuals. The greater the distance from or between source populations, the lower the probability of a habitat patch or group of patches to continue supporting that species. If the distance between occupied segments becomes too great, or if barriers prevent inter-segment movement, local extinctions are inevitable in the isolated segments. Thus, any reduction in the capacity of segments to support populations or subpopulations increases the probability of local extinctions in that segment, as well as in all other "downstream" segments to the west.

*Importance of the Missing Middle to Corridor Function*

This understanding of overall corridor function highlights the importance of the Missing Middle as a part of larger home ranges for more area-dependent species and for maintaining species use of segments farther west. Although there has been much attention to maintaining or improving road-crossing structures and avoiding new impediments to movement, there should be equal attention to maintaining functional habitat blocks, capable of supporting source populations of target species, within the Missing Middle. Currently, the eastern half of the Missing Middle (Tonner Canyon) serves as an extension of the large Chino-Tonner subcore, contributing dispersing individuals of target species to other segments. Likewise, Segment 3 (Shell-Aera), although somewhat smaller and degraded by grazing, undoubtedly supports significant numbers of target species that disperse (at some risk) across Harbor Boulevard into Powder Canyon and beyond.

## *Future Corridor Functions*

The above assessment of population distribution and movements, as summarized in Table 4, can serve as a foundation for assessing likely effects of future projects on the functionality of individual segments or the wildlife corridor as a whole. Although it is beyond the scope of this report to comprehensively analyze any particular project, I qualitatively assessed the likely effects of several proposed projects using the conceptual model presented above. I selected three proposed projects that most threaten corridor function in the Missing Middle and may eliminate wildlife populations and ecosystem functions throughout a much greater area of the Puente and Chino Hills. By impeding species movements or metapopulation dynamics within this peninsula of wild, a project's impacts may extend far beyond its boundaries, potentially rippling through the range of hills to eliminate wildlife populations as far west as the Whittier Hills.

*Shell-Aera Master Planned Community*

This planned community of 3,600 homes would be scattered over most of Segment 3 and the westernmost portion of Segment 2, straddling Highway 57 and extending west to Harbor Boulevard. Although detailed development plans and environmental analyses are not yet available, I obtained the conceptual development plan shown in Figure 5. (See http://hillsforeveryone.org/PDF_Files/aera_proposal.pdf for another version of the conceptual plan, which shows additional roads and features not included on Figure 5.)

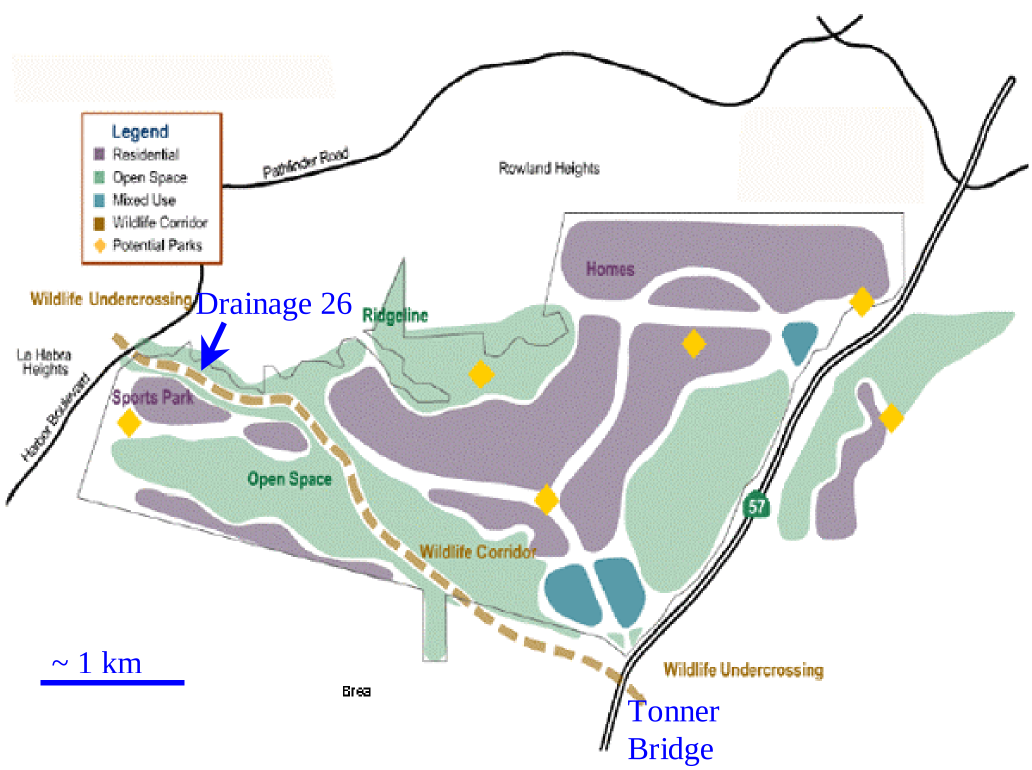



**Figure 5.** Conceptual development plan for the Shell-Aera Master Planned Community.

Although this conceptual plan appears to show approximately half the property as open space, it is clear that this open space represents far less than 50% of the property's biological value, due to severe fragmentation and edge effects, disruption of movements, and elimination of live-in habitat. Much of the open space would be totally isolated between bubbles of development and roads, such as the open space bubble on the west side of Highway 57. This and other open space patches would be completely isolated from other habitat areas, removing their capacity to support target species and other native wildlife. Moreover, the narrow and highly convoluted bits of open space depicted in this plan would suffer severe edge effects, greatly reducing the area's ability to support wildlife and ecological processes. As just one example, Argentine ants routinely invade several hundred meters from suburban edges into native scrub habitats, and even farther in moist drainages and canyons (Suarez et al. 1998). The open space bubbles are all less then 1 km across—much less in many places. Consequently, most if not all of the open space depicted in Figure 5 will be invaded by Argentine ants, which eliminate numerous native arthropods, plants, and vertebrates (such as the horned lizard) in a process of ecological collapse already well-documented in Southern California ecosystems (Suarez et al. 1998). In conclusion, only a minor fraction of remaining habitat will remain biologically useful in this proposed development area, and even that would be highly degraded relative to existing conditions.

The conceptual plan appears to be sensitive to wildlife movement needs in its depiction of a continuous "Wildlife Corridor" across the property, from Tonner Bridge through Drainage 26, to the location of the new wildlife tunnel being constructed under Harbor Boulevard. However, this characterization, apparently based on the primary movement corridor across the property as mapped by PCR (2002), is simplistic and biologically misleading. As concluded in the above review of corridor functions, long, narrow gauntlets of "move-through" habitat will not ensure continued functionality of the corridor system, which depends heavily on retaining the large blocks of live-in habitat in the Missing Middle. The mapped open-space corridor is about 4.5 km long and averages less than 500 m wide, which is insufficient to provide reliable live-in habitat for mountain lions and bobcats, for example. This is especially true considering that Segments 4 and 5 are also rather narrow and edge-effected, with marginal capacity to support foraging mountain lions or a subpopulation of bobcats. The overall result would be about 13 km of mostly linear, edge-effected, move-through habitat for these species, from live-in habitat east of Highway 57 to the next reliable foraging or subpopulation area in the Whittier Hills. The likelihood of continued movements by at least bobcats and mountain lions between Tonner Canyon and Whittier Hills would therefore drop dramatically with this development scenario.

In conclusion, this proposed housing development would seriously degrade the ability of Segment 3, and all segments farther west, to continue supporting target species, including mountain lion and bobcat. This would have cascading effects on flora and fauna in segments farther west, especially when considered in context with the relatively small and edge-effected Segments 4 and 5 it connects to on the west. Mule deer populations may, at least temporarily, increase in westerly segments like the Whittier Hills, due to removal of mountain lions from the system. In the short term, this may result in increased car-deer collisions on local roads; but in the long term, even deer are likely to disappear from all segments west of Highway 57 due to isolation of this relatively small population.

*Tres Hermanos Reservoirs*

This series of three reservoirs proposed by the City of Industry in Tonner Canyon (Figure 6) would also have substantial adverse impacts on corridor function. The upper Tonner Canyon

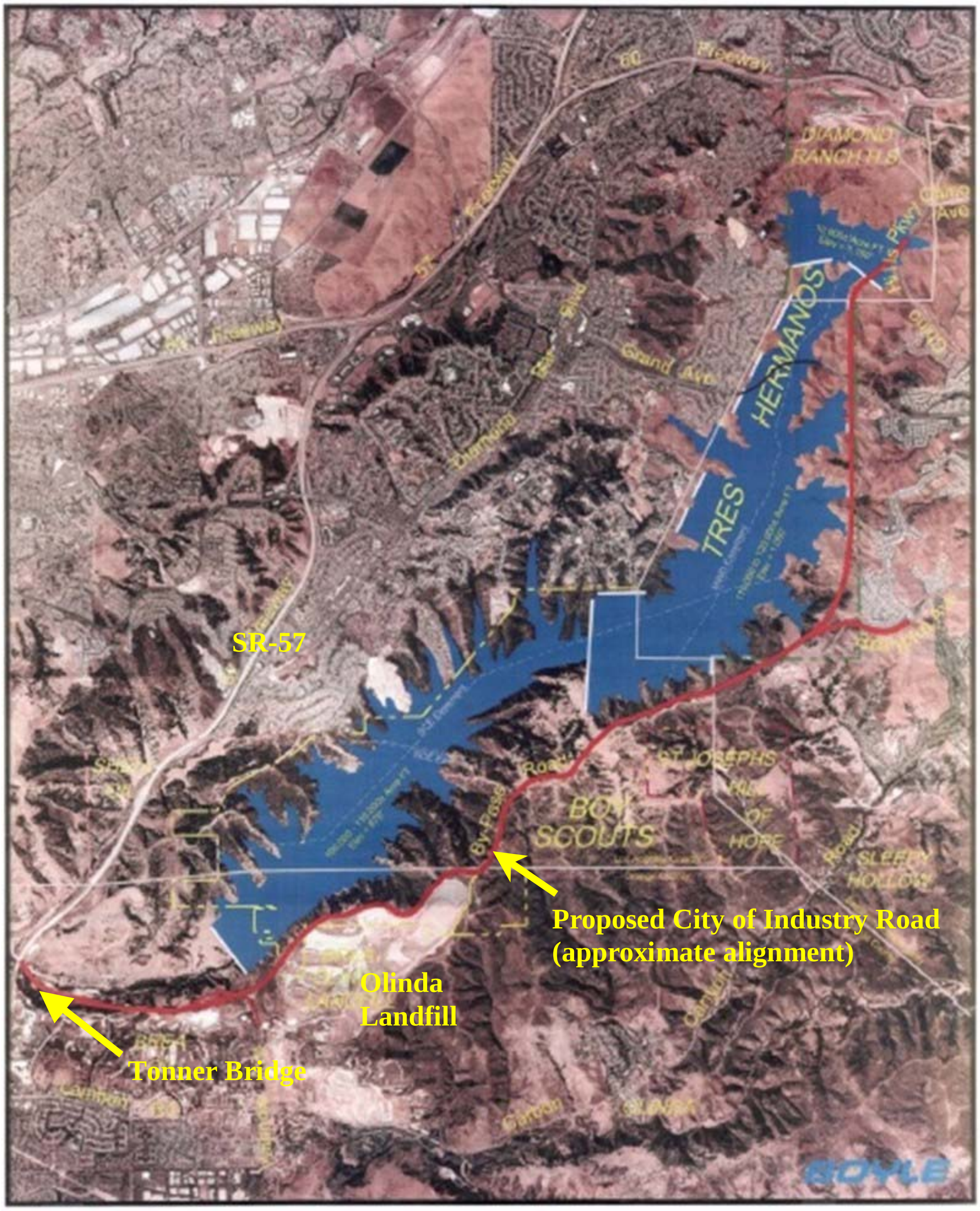



**Figure 6.** Aerial photograph showing City of Industry's proposed Tres Hermanos reservoirs and new road in Tonner Canyon.

area (northeast of the Firestone Scout Reservation), although supporting some target species and other wildlife, is mostly open grassland and somewhat degraded in habitat quality. Although a reservoir confined to this upper area would incrementally reduce the size of this segment and its capacity to support target species populations, it is far enough removed from the primary corridor connection across the Missing Middle that it would have less effect on overall corridor function than other developments I considered. However, any development (for reservoirs or other purposes) in middle and especially lower Tonner Canyon could have severe impacts on corridor function, especially if they reduced use of the Tonner Canyon Bridge on Highway 57. Any development that blocked access to or through the bridge area would make Highway 57 a barrier to wildlife and likely lead to wildlife extirpations in segments farther west.

At the very least, creation of these reservoirs would incrementally reduce the size of what is now a large Chino-Tonner subcore. Tonner Canyon, representing the westernmost portion of this subcore, is the primary source habitat for animals dispersing into the rest of the corridor system to the west. Hence, the location of this project would magnify its relative impact on continued corridor function by increasing the distance wildlife would have to move from source habitat areas to other segments.

*Proposed City of Industry Road*

Figure 6 also shows an approximate, conceptual alignment for a proposed road parallel to Tonner Canyon (see also Maps 1 and 2). Although I found no specifications for this road or associated development, it would appear to be a major throughway connecting Highway 57 (from the existing Tonner Bridge intersection) to Highway 60 across the widest portion of the Puente-Chino Hills Wildlife Corridor. Based on its location, the road would require major cut and fill to construct. Perhaps most troubling is its connection at the critical Tonner Bridge wildlife undercrossing. Depending on design, this is highly likely to render this last remaining corridor connection non-functional for mountain lion, deer, bobcat, and numerous other species. Even if this connection could be engineered to retain a functional wildlife undercrossing, the road could severely impact wildlife populations and movements along a broad front. A series of additional undercrossings (or overcrossings) and extensive wildlife fencing would need to be incorporated along the length of the road, or else most of Tonner Canyon would be isolated between two barrier roads (this one and Highway 57) or wildlife would suffer severe roadkill impacts. Approximately 21.2 sq. km of grasslands, forests, and shrublands would be segregated from the large and valuable Chino-Tonner subcore, incrementally diminishing its capacity to support wildlife populations. At best, what is now a broadly contiguous block of habitat would be reduced to a narrow and more edge-effected funnel across the Olinda Landfill to the Tonner Bridge.

*Cumulative Effects*

A full impact analysis for any or all of these proposed projects would need to address cumulative impacts on wildlife populations and movements through the corridor, which is beyond the scope of this report. Among these cumulative impacts would be inducement of further development, such as additional residential, commercial, or industrial development along the road. Increased traffic (and hence roadkill) would also need to be analyzed and mitigated for. Any combination of two or more of these projects would likely render the Puente-Chino Hills Wildlife Corridor non-functional west of Olinda Landfill, regardless of mitigation.

# Discussion

Before summarizing conservation and restoration recommendations for the Missing Middle, this section reviews the literature on the functions and benefits of wildlife corridors in conservation, including criticisms of corridor conservation.

## *Functions and Benefits of Wildlife Corridors*

> "Connectivity is not just another goal of conservation: it is the natural state of things."
>
> Michael Soulé & John Terborgh (1999)

Landscape linkages and wildlife movement corridors vaulted to the forefront of conservation thinking in recent decades, in response to rising recognition that habitat fragmentation is a principal cause of species extinction and endangerment (Willis 1974, Diamond 1975, Wilson and Willis 1974, Noss 1983, Wilcox and Murphy 1985, Forman 1991, Harrison 1992, Rosenberg et al. 1997). Habitat connections or movement corridors connecting reserves or larger "core areas" of habitat are thought to counter many adverse effects of isolation by fragmentation on species and ecological processes (Preston 1962, Noss 1983, 1987, Soulé 1991, Meffe and Caroll 1994, Rosenberg et al. 1997, Soulé and Terborgh 1999, Beier et al. in press). Although some critics have argued that there are costs as well as benefits to conserving corridors, and that under certain circumstances creating or maintaining corridors could even harm some species or communities (e.g., Simberloff and Cox 1987, Simberloff et al. 1992, Hess 1994), the overwhelming weight of scientific evidence is that maintaining connectivity is generally beneficial, especially for those species and ecological communities for which connectivity "is the natural state of things" (Soulé and Terborgh 1999). Certainly, for most species and ecological communities, maintaining connectivity is less risky than losing connectivity (Hobbs 1992, Beier and Noss 1998, Soulé and Terborgh 1999).

## *Assessing Connectivity Pros and Cons*

> "Those who would destroy the last remnants of natural connectivity should bear the burden of proving that corridor destruction will not harm target populations."
>
> Paul Beier & Reed Noss (1998)

This section reviews specific arguments for and against conserving corridors and how they apply to the Puente-Chino Hills. As elaborated below, in most cases, arguments against corridor conservation are really just cautions against applying corridors as a panacea for conservation, in recognition that there may be special cases where connecting reserves could cause more harm than good or where other approaches to conservation may be more effective or cost-effective (for example, enlarging core reserves rather than connecting existing reserves). These special cases do not apply to the Puente-Chino Hills Wildlife Corridor, where maintaining connectivity would clearly provide net benefits for biological diversity and ecosystem health in these hills. Given that the weight of scientific evidence favors connectivity here, whether and how connectivity can be assured is a societal issue not addressed in this scientific treatment.

The potential disadvantages of creating or maintaining wildlife movement corridors include several ecological arguments and one financial argument (Simberloff and Cox 1987, Simberloff et al. 1992, Hobbs 1992, Hess 1994):

1. Corridors may serve as conduits for the spread of deleterious species, like invasive pests, weeds, or predators.
2. Corridors may serve to spread detrimental processes—such as wildfire or disease—to or among reserve areas.[6]
3. Corridors may facilitate movements by highly mobile animals between reserves even without corridors. (Or, these species may be overly abundant in urban interface areas due to imbalanced ecological conditions.) But corridors may not help movement for more sedentary or at-risk species, for which other conservation approaches may work better than corridors.
4. Corridors could act as population "sinks" (Pulliam 1988), attracting individuals from higher quality habitat areas into edge-effected habitats where death rates exceed birth rates. If this effect is strong enough, it can reduce the regional abundance of the species, or even increase extinction probabilities for a rare species.
5. Corridors may be expensive to create or maintain and may not represent the optimal allocation of limited funding relative to, for example, increasing the size or management of existing core areas.

Note that in one way or another, all of these potential disadvantages hinge on relative comparisons of potential risks and benefits of maintaining vs. losing connectivity. Also, as pointed out by numerous researchers, the risks and benefits of corridors will vary by species. In the sections below, I briefly evaluate these potential disadvantages as they may apply within the Puente-Chino Hills Wildlife Corridor for target species of interest.

*Conduits for Deleterious Species*

It is difficult to envision how any deleterious species might increase its distribution or adverse effects due to conserving additional lands in this existing archipelago of open space reserves. Connecting these areas with additional conservation would not increase rates with which annual weeds, Argentine ants, rats, house mice, or other potential pest species invade open space areas relative to existing conditions. Sources of such deleterious species are nearly ubiquitous in Southern California, due to existing human land use patterns. Maintaining an existing open space corridor system would not facilitate expansions of such species, either from the more urbanized western portions of the study area into the Santa Ana Mountains, or vice versa, and may even help counter further invasions (relative to more roads or development in the area).

[6] Although wildfire and disease are natural disturbance processes in ecosystems, changes wrought by humans, such as habitat fragmentation and increased fire frequencies in urban interface areas, may create situations where these natural processes cause unnatural harm to biological resources. Corridors could help spread these deleterious effects.

*Conduits for Deleterious Processes*

Again, it is difficult to conceive how maintaining connectivity in this context could contribute to the spread of deleterious processes. This argument is generally based on the assumption that a new corridor is being *created* (e.g., connecting what are naturally unconnected habitat areas) rather than maintaining "the natural state of things" with an existing, natural corridor (Beier and Noss 1998). As with the argument concerning deleterious species, this seems not to be an issue for the Puente-Chino Hills Wildlife Corridor. Although diseases or parasites may be carried between habitat segments by wildlife, this already occurs and always did. Although fires may spread from one segment to another under certain conditions, the area is already highly segmented by fire breaks in the form of existing roads and other discontinuities. In fact, given the nature of Southern California's most destructive wildfires, which are driven by Santa Ana wind conditions (Keeley and Fotheringham 2001, Keeley et al. 1999, Halsey 2004), fire provides a stronger argument for not building more homes in wildland areas, rather than an argument for not conserving wildland areas.

*Ineffectiveness for Rare or Sedentary Target Species*

This is clearly a non-argument for the Puente and Chino Hills. Target species selected for review in this report, including both rare and common species, are highly sensitive to habitat fragmentation and benefit from corridor conservation (e.g., Beier 1993, Beier et al. in press, Crooks 2002, Ng et al. 2004). Although some rare or more sedentary species may not benefit directly from corridor conservation here (e.g., some reptile and amphibian species already lost from western segments of the corridor), the ecological benefits that accrue from corridor conservation for the remaining flora and fauna are indisputable. Indeed, research in the Puente-Chino Hills Wildlife Corridor reinforces other research indicating that more common, insensitive, and "pesky" wildlife like skunks and raccoons actually increase in density with reductions in larger carnivores like mountain lions and bobcats, due to losses of landscape connectivity (Haas 2000, Crooks and Soulé 1999). Countering this process of "meso-predator release" (Crooks and Soulé 1999), and the cascade of species losses and other adverse ecological changes that it can bring, is a strong argument for maintaining the Puente-Chino Hills Wildlife Corridor for mountain lions, coyotes, and bobcats.

*Population Sinks*

This is a legitimate argument that deserves analysis. It may be that, especially for species highly prone to roadkill, mortality in the Puente and Chino Hills is elevated relative to larger, more contiguous areas like the Santa Ana Mountains. It is conceivable that the corridor therefore serves as a "population sink" (Pulliam 1988), where animals enter the corridor from larger or higher quality habitats, only to be killed. However, the potential for this effect to substantially reduce regional wildlife populations in the Santa Ana Mountains seems remote. Moreover, the benefits of these species living within the Puente and Chino Hills, even with elevated mortality rates, are immense, both to ecological health and to quality of life for local human residents.

*Suboptimal Conservation Investment*

This is a non-argument for this study area. Given the current wildland-development pattern that exists, there is no alternative to corridor conservation and restoration for retaining species populations and maintaining healthy ecological processes in this area. Although one could argue that further investment in conserving these hills could be better spent elsewhere (e.g., enlarging larger wilderness reserves in Southern California mountains), this would come at the detriment of maintaining a unique ecological classroom full of wildlife in close proximity to millions of people craving a connection with nature. According to the California Department of Parks and Recreation, nearly a quarter billion dollars have already been spent on open space conservation in the Puente and Chino Hills, and this investment could be for naught if additional conservation fails to secure a continuous corridor from the Santa Ana Mountains to the Whittier Hills.

## Mitigating Road Effects

> "Nothing is worse for sensitive wildlife than a road."
>
> Reed Noss

Roads or the traffic they carry kill animals directly (roadkill), disrupt natural migration and movement patterns, interfere with species communication, change water runoff and flow patterns, and create air, water, and soil pollution (Trombulak and Frissell 2000, Forman and Deblinger 2000, Jones et al. 2000, Reijnen et al. 1997). During Beier's (1993, 1995) study of mountain lions in the Santa Ana Mountains, vehicles killed 33% of the population, including four lions killed at one road-crossing during a 2-year period.

The growing awareness of road impacts on environmental health and imperiled species has created a burgeoning literature on efforts to mitigate these effects with improved wildlife road-crossing structures. Wildlife crossing structures have proved successful in the United States and elsewhere (Transportation Research Board 2002). The main types of structures, from most to least effective, are vegetated land-bridges, bridges, underpasses, and culverts.

About 50 vegetated wildlife overpasses, ranging from 50 m (164 ft) to over 200 m (656 ft) wide, have been built in Europe, Canada, and the U.S. (Evink 2002, Forman et al. 2003). Soil (0.5 to 2 m deep) covers the overpasses, which are planted, usually with native vegetation (Jackson and Griffin 2000). Overpasses are quieter than underpasses and maintain ambient conditions (Jackson and Griffin 2000), so they may be less intimidating for some species than dark tunnels. In Banff Provincial Park, large mammals preferred overpasses to other crossing structures (Forman et al. 2003). Similarly, birds, butterflies, and other open-air wildlife are more likely to use overpasses than underpasses.

Bridges are also effective crossing structures, especially if wide enough to permit growth of both riparian and upland vegetation along stream banks (Jackson and Griffin 2000, Evink 2002, Forman et al. 2003). Bridges with greater openness ratios are generally more successful than low bridges and culverts (Veenbaas and Brandjes 1999, Jackson and Griffin 2000). The Tonner Bridge is a good example of a broad, open bridge with natural vegetation beneath. My observations reinforce those of previous biologists that maintaining access through this structure, and perhaps improving habitat conditions on either side, is critical to the flow of large mammals across the Puente-Chino Hills landscape.

Although inferior to bridges, culverts and other tunnel-like structures can be effective for some species (Jackson and Griffin 2000). Only very large culverts (such as box culverts and equestrian tunnels) are effective for large mammals (Lyren 2001, Haas 2000, Gloyne and Clevenger 2001). Gloyne and Clevenger (2001) suggest that underpasses for ungulates should be at least 4.27 m high and 8 m wide, with an openness ratio of 0.9 (where the openness ratio = height x width/length). Earthen flooring is preferable to concrete or metal (Evink 2002).

In places where a bridged, vegetated under-crossing or over-crossing is not feasible, placing pipe culverts alongside box culverts can help serve movement needs of both small and large animals. Special crossing structures that allow light and water to enter the structure have been designed to accommodate amphibians.

Noise, artificial night lighting, traffic noise, and other disturbances can deter animal use of a crossing structure (Yanes et al. 1995, Clevenger and Waltho 1999, Forman et al. 2003). Shrub or tree cover can help funnel wildlife to a passage while hiding them or making them feel more secure when approaching crossing structures (Evink 2002, Forman et al. 2003). Regardless of crossing type, wildlife fencing is necessary to funnel animals towards road-crossing structures and keep them off the road surface (Falk et al. 1978, Ludwig and Bremicker 1983, Feldhammer et al. 1986, Haas 2000, Lyren 2001, Forman et al. 2003). Earthen one-way ramps can allow animals that wander into the right-of-way to escape over the fence (Bekker et al. 1995, Forman et al. 2003).

# Conclusions and Recommendations

## *Conservation and Restoration Priorities for the Missing Middle*

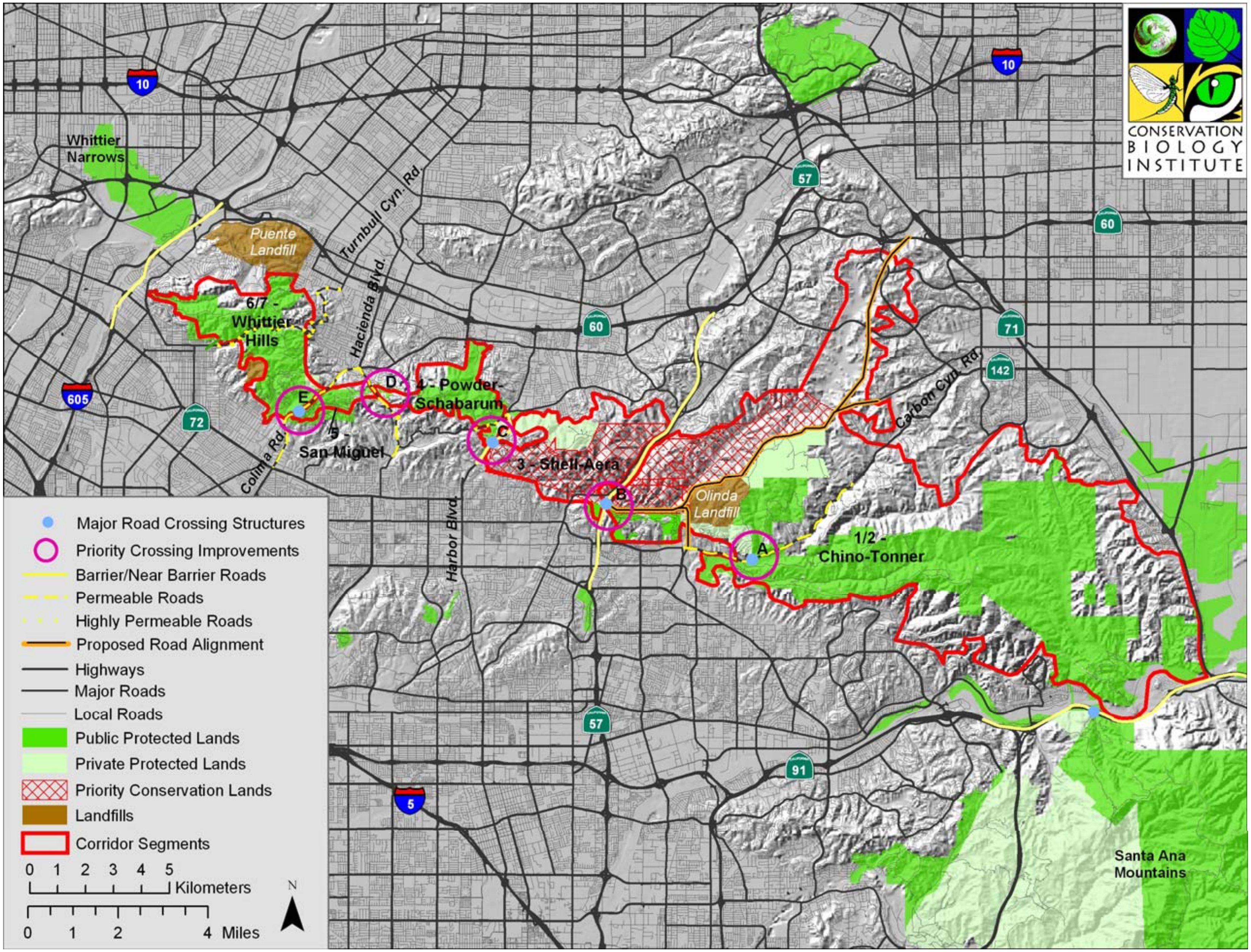
Based on the analysis of corridor function, Map 3 shows locations of priority conservation and restoration actions in and near the Missing Middle. This is by no means a comprehensive summary of all necessary and sufficient actions to maintain or improve biological conditions throughout the Puente-Chino Hills landscape. Rather, it focuses on those locations and actions that seem most critical to maintaining functional connectivity across the Puente-Chino Hills Wildlife Corridor based on the metapopulation analysis.

These recommendations are redundant with those from previous studies, especially concerning the need to secure and improve unimpeded movement by large target species across roads. This should not be surprising, because information on the characteristics and functioning of these corridor segments is quite consistent across studies. Perhaps the greatest benefit of the meta-analysis provided in this report is a renewed focus on the need to conserve not just unimpeded movement, but an archipelago of relatively large habitat blocks with sufficient carrying capacity to ensure continued presence of viable populations through this range of hills. Road-crossings are just one part of the story.

**Priority Conservation Lands**

Conserving intact habitat blocks within the red-hatched lands on Map 3 is essential to maintaining functional metapopulation dynamics for target species throughout the Puente-Chino Hills Wildlife Corridor. As supported by the geographic unit analysis, the capacity of Segments 2 and 3—from Chino Hills State Park to Harbor Boulevard—to support robust populations of target species and live-in habitat for mountain lions is essential to keeping these species in the study area, all the way to Whittier Hills. Essentially all of the Shell-Aera property, and at least the lower 1/2 to 2/3 of the City of Industry lands in Tonner Canyon, are of high priority for conservation.

Note that the line separating high-priority conservation lands in mid- to lower Tonner Canyon from upper Tonner Canyon is somewhat arbitrary. But the farther up Tonner Canyon one goes, the less essential habitat becomes for ensuring corridor functionality. (Note, however, that Cooper [2000] considered upper Tonner Canyon a high conservation priority for native birds, especially grassland species like raptors and grasshopper sparrows.) I established the northeast boundary of the Tonner Canyon high-priority conservation area primarily to consolidate a contiguous reserve along with the existing Firestone Scout Reservation and Chino Hills State Park. Extending this boundary farther north would increase biological benefits even more, but with decreasing marginal returns for corridor function.




Map 3. Conservation and restoration priorities in the vicinity of Missing Middle.

Essentially all of the Shell-Aera property west of Highway 57 is extremely high priority for conserving corridor integrity. Based on metapopulation analysis, conserving a "move-through corridor" across this property, as depicted in Figure 5, is not enough to ensure continued target species presence through the corridor system. Given this segment's location between two near-barrier roads, and the relatively narrow and constrained status of Segments 4 and 5 to the west, securing a large, intact habitat block capable of supporting populations or subpopulations of target species is essential here. Moreover, this segment could benefit greatly from habitat management and restoration to increase carrying capacity for target species, and thereby to decrease the probability of species extirpations here and all the way to the Whittier Hills.

**Priority Crossing Improvements**

Map 3 shows five priority road-crossing improvements with magenta circles, labeled A through E from east to west. Most of these recommendations have already been made by others (e.g., Haas 2000), and some may already have been acted on or are in planning stages. At the risk of redundancy, I nevertheless recommend the following improvements in these general locations. Refer to Haas (2000) for additional recommendations and details:

A. Add wildlife fencing on either side of Carbon Canyon Road to reduce roadkill and encourage wildlife to use existing culverts, especially the concrete box culvert near the entrance to Chino Hills State Park. Adding another wildlife crossing structure, designed to accommodate all large mammals, would be even better. Given that traffic on this 2-lane road is increasing due to increasing development in the vicinity (Haas 2000), any future road upgrades should incorporate bridges or other very open wildlife crossing structures as mitigation. A variety of smaller under-crossings with funneling fences, specifically designed to accommodate smaller reptiles, amphibians, and mammals, should also be considered to improve connectivity for these species.

B. Prohibit any development that would increase traffic under the Tonner Bridge or add any new impediments (structures, lights, noise, etc.) to the vicinity of the bridge. Restore riparian vegetation along Tonner Creek, where degraded by oil development activities. Fence along Highway 57 if monitoring suggests road mortality is high.

C. A wildlife underpass tunnel is to be constructed here under Harbor Boulevard, but recommended fencing has apparently not been allowed by a property owner (A. Henderson, personal communication). Secure rights to install wildlife fencing along both sides of Harbor Boulevard to reduce roadkill and ensure maximum utility of the wildlife tunnel. Plant native shrubs and trees on either side of the tunnel to provide cover to wildlife approaching the entrances. Consider adding smaller under-crossings and funneling fences to accommodate smaller reptiles, amphibians, and mammals.

D. Secure remaining "at-risk" parcels in this narrow, constricted portion of the corridor, west of Powder Canyon and Schabarum Regional Park. Enlarge or otherwise improve the existing equestrian tunnel to enhance its use by wildlife, including adding screening vegetation, especially on the western end. Fence either side of the tunnel to help funnel wildlife to it. However, extensive fencing along Hacienda Boulevard is not recommended, because most large mammals currently cross at-grade. Although Hacienda Boulevard currently has moderate traffic at relatively low speeds, and therefore relatively low roadkill (Haas 2000), road improvements or increases in traffic could make the situation worse. In this case, consider building a wildlife overpass (a vegetated wildlife bridge) over Hacienda Boulevard, taking advantage of steep slopes rising up from either side of the road. Given this terrain, a vegetated overpass somewhere between Skyline Drive and the equestrian tunnel may be feasible and would certainly be superior to culverts or other underpass structures in accommodating wildlife movement. Consider also adding smaller under-crossings and funneling fences to accommodate smaller reptiles, amphibians, and mammals.

E. Maintain and improve the Colima Service Tunnel as a critical wildlife underpass. Add fencing or screening vegetation, if necessary, based on further site-specific inspection or monitoring. Limit and mitigate for any actions that may increase traffic, light, noise, or human activity in the vicinity of the Service Tunnel from sunset to sunrise, when wildlife use is most frequent. Consider also adding smaller under-crossings and funneling fences to accommodate smaller reptiles, amphibians, and mammals.

# References Cited


Beier, P. 1993. Determining minimum habitat areas and habitat corridors for cougars. Conservation Biology 7:94-108.

Beier, P. 1995. Dispersal of juvenile cougars in fragmented habitat. J. Wildlife Management 59:228-237.

Beier, P., and R. Noss. 1998. Do habitat corridors provide connectivity? Conservation Biology 12:1241-1252.

Beier, P., K. Penrod, C. Luke, W. Spencer, and C. Cabanero. In press. South Coast Missing Linkages: restoring connectivity to wildlands in the largest metropolitan area in the United States. *In:* Crooks, K., and Sanjayan, M. (eds.), Connectivity conservation. Cambridge University Press.

Bekker, H., B. van den Hengel, H. van Bohmen, and H. van der Sluijs. 1995. Natuur over wegen (Nature across motorways). Ministry of Transport, Public Works and Water Management, Delft, Netherlands.

Brown, J.H., and A. Kodric-Brown. 1977. Turnover rates in insular biogeography: effect of immigration on extinction. Ecology 58:445-449.

Case, T., and R. Fisher. 1998. Inventories of the herpetofauna of the Chino-Puente Hills, and identification of important conservation priorities. Unpublished report. Department of Biology, University of California, San Diego, CA.

Clevenger, A.P., and N. Waltho. 1999. Factors influencing the effectiveness of wildlife underpasses in Banff National Park, Alberta, Canada. Conservation Biology 14:47-56.

Clevenger, A.P., B. Chruszcz, and K. Gunson. 2001. Drainage culverts as habitat linkages and factors affecting passage by mammals. Journal of Applied Ecology 38:1340-1349.

Cooper, D.S. 2000. Breeding landbirds of a highly threatened open space: the Puente-Chino Hills, California. Western Birds 31:213-234.

Crooks, K.R. 2002. Relative sensitivities of mammalian carnivores to habitat fragmentation. Conservation Biology 16:488-502.

Crooks, K.R., A.V. Suarez, D.T. Bolger, and M. Soulé. 2001. Extinction and colonization of birds on habitat islands in urban Southern California. Presentation at Society of Conservation Biology Conference, Fragmented Habitats and Bird Conservation Session, Hilo, HI.

Crooks, K.R., and M.E. Soulé. 1999. Mesopredator release and avifaunal extinctions in a fragmented system. Nature 400:563-566.

Decision Research. 2003. Poll of 700 residents concerning open space in the vicinity of the Puente and Chino Hills. Poll 2037. March 23-26, 2003.

Diamond, J.M. 1975. The island dilemma: lessons of modern biogeographic studies for the design of natural reserves. Biological Conservation 7:129-146.

Evink, G.L. 2002. Interaction between roadways and wildlife ecology. National Academy Press, Washington, DC.

Falk, N.W., H.B. Graves, and E.D. Bellis. 1978. Highway right-of-way fences as deer deterrents. Journal of Wildlife Management 42:646-650.

Feldhammer, G.A., J.E. Gates, D.M. Harmon, A.J. Loranger, and K.R. Dixon. 1986. Effects of interstate highway fencing on white-tailed deer activity. Journal of Wildlife Management 50:497-503.

Fisher, R.N., A.V. Suarez, and T.J. Case. 2002. Spatial patterns in the abundance of the coastal horned lizard. Conservation Biology 16:205-215.

Forman, R.T.T. 1991. Landscape corridors: from theoretical foundations to public policy. Pages 71-84 *in* Saunders, D.A., and R.J. Hobbs (eds.), Nature conservation 2: the role of corridors. Surrey Beatty & Sons PTY Limited, Chipping Norton.

Forman, R.T.T. 2000. Estimate of the area affected ecologically by the road system in the United States. Conservation Biology 14:31-35.

Forman, R.T.T., and R.D. Deblinger. 2000. The ecological road-effect zone of a Massachusetts (U.S.A.) suburban highway. Conservation Biology 14:36-46.

Forman, R.T.T., D. Sperling, J.A. Bissonette, A.P. Clevenger, C.D. Cutshall, V.H. Dale, L. Fahrig, R. France, C.R. Goldman, K. Heanue, J.A. Jones, F.J. Swanson, T. Turrentine, and T.C. Winter. 2003. Road ecology: science and solutions. Island Press, Washington, DC.

Garrett, K., and J. Dunn. 1981. Birds of Southern California: status and distribution. Los Angeles Audubon Society, Los Angeles, CA.

Gloyne, C.C., and A.P. Clevenger. 2001. Cougar (*Puma concolor*) use of wildlife crossing structures on the Trans Canada highway in Banff National Park, Alberta. Wildlife Biology 7(2):117-124.

Haas, C.D. 2000. Distribution, relative abundance, and roadway underpass responses of carnivores throughout the Puente-Chino Hills. Unpubl. M.S. Thesis. California State Polytechnic University, Pomona, CA. 110 pp.

Haas, C.D., and K. Crooks. 1999. Carnivore abundance and distribution throughout the Puente/Chino Hills. Final Report. Prepared for The Mountains Recreation and Conservation Authority and State of California Department of Transportation.

Haas, C.D., A.R. Backlin, C. Rochester, and R.N. Fisher. 2002. Monitoring reptiles and amphibians at long-term biodiversity monitoring stations: The Puente-Chino Hills. Final Report. Prepared for Mountains Recreation and Conservation Authority, Puente Hills Landfill Native Habitat Preservation Authority, and California State Parks.

Haas, C.D., and Turschak, G. 2002. Responses of large and medium-bodied mammals to recreation activities: the Colima Road Underpass. Final Report. Prepared for Puente Hills Landfill Native Habitat Preservation Authority. U.S. Geological Survey, Western Ecological Research Center.

Halsey, R. 2004. Fire, chaparral, and survival in Southern California. Sunbelt Publications, San Diego, CA. 188 pp.

Harrison, R.L. 1992. Toward a theory of inter-refuge corridor design. Conservation Biology 6:293-295.

Hess, G. 1994. Conservation corridors and contagious disease: a cautionary note. Conservation Biology 8:256-262.

Hobbs, R.J. 1992. The role of corridors in conservation: solution or bandwagon? Tree 7:389-391.

Horn, M., M. Carlin, T.L. Eagan, M. Erickson, C. Jones, W. Loeffler, and G. Nishiyama. 1993. A regional landscape approach to maintaining biodiversity: protected areas in Orange County and environs. Pages 69-83 *in* Keeley, J.E. (ed.), Interface between ecology and land development in California. Southern California Academy of Sciences, Los Angeles, CA.

Jackson, S.D., and C.R. Griffin. 2000. A strategy for mitigating highway impacts on wildlife. Pages 143-159 *in* Messmer, T.A., and B. West (eds.), Wildlife and highways: seeking solutions to an ecological and socio-economic dilemma. The Wildlife Society.

Jones, J.A., F.J. Swanson, B.C. Wemple, and K.U. Snyder. 2000. Effects of roads on hydrology, geomorphology, and disturbance patches in stream networks. Conservation Biology 14:76-85.

Keeley, J.E., and C.J. Fotheringham. 2001. Historic fire regime in Southern California shrublands. Conservation Biology 15:1536-1548.

Keeley, J.E., C.J. Fotheringham, and M. Morais. 1999. Reexamining fire suppression impacts on brushland fire regimes. Science 284:1829-1832.

Lembeck, M. 1978. Bobcat study, San Diego County, California. California Department of Fish and Game Project E-W-2, Study IV, Job 1.7. September. 21 pp.

LSA Associates, Inc. 2005. Draft resource management plan. Prepared for Puente Hills Landfill Native Habitat Preservation Authority. February.

Ludwig, J., and T. Bremicker. 1983. Evaluation of 2.4-m fences and one-way gates for reducing deer-vehicle collisions in Minnesota. Transportation Research Record 913:19-22.

Lyren, L.M. 2001. Movement patterns of coyotes and bobcats relative to roads and underpasses in the Chino Hills area of Southern California. Unpubl. M.S. Thesis, California State Polytechnic University, Pomona, CA. 127 pp.

Meffe, G.K., and C.R. Carroll. 1994. The design of conservation reserves. Pages 265-306 *in* Meffe, G.K., and C.R. Carroll (eds.), Principles of conservation biology. Sinauer Associates, Sunderland, MA.

Ng, S.J., J.W. Dole, R.M. Sauvajot, S.P.D. Riley, and T.J. Valone. 2004. Use of highway undercrossings by wildlife in Southern California. Biological Conservation 115:499-507.

Noss, R. 1983. A regional landscape approach to maintain biodiversity. BioScience 33:700-706.

Noss, R. 1987. Protecting natural areas in fragmented landscapes. Natural Areas Journal 7:2-13.

Noss, R., P. Beier, and W. Shaw. 1997. Evaluation of the Coal Canyon biological corridor. Unpublished report.

PCR Services Corporation, Frank Hovore & Associates, and FORMA Systems. 2000. Executive summary of the proposed Los Angeles County Significant Ecological Areas. Prepared for Los Angeles County Department of Regional Planning. November.

PCR Services Corporation. 2002. Biological constraints analysis: Aera Master Planned Community. Prepared for Los Angeles County Regional Planning, Los Angeles, CA. April.

Preston, F. 1962. The canonical distribution of commonness and rarity. Ecology 43:185-215, 410-432.

Pulliam, H.R. 1988. Sources, sinks, and population regulation. American Naturalist 132:652-661.

Quinn, R.D. 1998. Status of California black walnuts (*Juglans californica*) at southern Puente Hills site. Unpublished report. June 12.

Reijnen, R., R. Foppen, and G. Veenbaas. 1997. Disturbance by traffic of breeding birds: evaluation of the effect and considerations in planning and managing road corridors. Biodiversity and Conservation 6:567-581.

Riley, S.P.D., R.M. Sauvajot, T.K. Fuller, E.C. York, D.A. Kamradt, C. Bromley, and R.K. Wayne. 2003. Effects of urbanization and habitat fragmentation on bobcats and coyotes in Southern California. Conservation Biology 17:566-576.

Robertson, G., D. Fretz, and D. Zacovic. 1995. Wildlife movement in the Puente-Chino Hills: potential pathways and impediments. Prepared for Wildlife Corridor Conservation Authority. January.

Rosenberg, D.K., B.R. Noon, and E.C. Meslow. 1997. Biological corridors: form, function, and efficacy. BioScience 47:677-687.

Schlotterbeck, M.M. 2001. GIS mapping of biological studies in the Puente-Chino Hills Wildlife Corridor, including species diversity and relative abundance. M.S. Project, California State University, Fullerton, CA. 49 pp.

Simberloff, D., and J. Cox. 1987. Consequences and costs of conservation corridors. Conservation Biology 1:63-71.

Simberloff, D., J.A. Farr, J. Cox, and D.W. Mehlman. 1992. Movement corridors: conservation bargains or poor investments? Conservation Biology 6:493-504.

Soulé, M.E. 1991. Land use planning for the maintenance of wildlife in a fragmenting urban landscape. Journal of the American Planning Association (Summer) 199:312-322.

Soulé, M.E., and J. Terborgh (eds.). 1999. Continental conservation: scientific foundations of regional reserve networks. Island Press. 227 pp.

Soulé, M.E., D.T. Bolger, A.C. Alberts, R. Sauvajot, J. Wright, M. Sorice, and S. Hill. 1988. Reconstructed dynamics of rapid extinctions of chaparral requiring birds in urban habitat islands. Conservation Biology 2:75-92.

Spencer, W.D., M.D. White, and J.A. Stallcup. 2001. On the global and regional ecological significance of southern Orange County: conservation priorities for a biodiversity hotspot. Unpublished report prepared for Endangered Habitats League. 44 pp.

Suarez, A.V., D.T. Bolger, and T.J. Case. 1998. The effects of fragmentation and invasion on the native ant community in coastal Southern California. Ecology 79:2041-2056.

Suarez, A.V., J.Q. Richmond, and T.J. Case. 2000. Prey selection in horned lizards following the invasion of Argentine ants in Southern California. Ecological Applications 10:711-725.

Tigas, L.A., D.H. Van Vuren, and R.M. Sauvajot. 2002. Behavioral responses of bobcats and coyotes to habitat fragmentation and corridors in an urban environment. Biological Conservation 108:299-306.

Transportation Research Board. 2002. Interaction between roadways and wildlife ecology—a synthesis of highway practice. National Cooperative Highway Research Program Synthesis 305.

Trombulak, S.C., and C.A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology 14:18-30.

Unitt, P. 2004. San Diego County Bird Atlas. San Diego Natural History Museum and Ibis Publishing Company, San Diego, CA.

Veenbaas, G., and J. Brandjes. 1999. Use of fauna passages along waterways under highways. *In* Evink, G.L., P. Garrett, and D. Zeigler (eds.), Proceedings of the 3rd international conference on wildlife ecology and transportation. FL-ER-73-99. Florida Department of Transportation, Tallahassee, FL.

Wilcox, B.A., and D.D. Murphy. 1985. Conservation strategy: the effects of fragmentation on extinction. American Naturalist 125:879-887.

Willis, E.O. 1974. Population and local extinctions of birds on Barro Colorado Island, Panama. Ecological Monographs 44:153-169.

Wilson, E.O., and E.O. Willis. 1975. Applied biogeography. Pages 522-534 *in* Cody, M.L., and J.M. Diamond (eds.), Ecology and evolution of communities. Harvard University Press, Cambridge, MA.

Yanes, M., J.M. Velasco, and F. Suarez. 1995. Permeability of roads and railways to vertebrates: the importance of culverts. Biological Conservation 71:217-222.