Effects of a purpose-built underpass on wildlife activity and traffic-related mortality in southern California: The Harbor Boulevard Wildlife Underpass

Submitted to:

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By:

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INTRODUCTION

Nearly 10 million people live in Los Angeles County, with an additional 3 million in neighboring Orange County. The human population in the region is growing at rate of approximately 5% (U. S. Census Bureau 2007), and as the human population grows, more open space is converted to urban and suburban uses. As a result, remaining tracts of native coastal sage scrub and chaparral wildlife habitat have become increasingly degraded, fragmented and isolated. Smaller, more isolated habitat patches tend to support fewer species and are less likely to contain area-sensitive species, especially medium- and large-sized mammalian carnivores (Crooks 2002, Hunter 2002). Moreover, natural areas in close proximity to urban areas tend to have more edge, lower quality habitat and increased human use, all of which can alter behavior of wildlife (Riley et al. 2003, George and Crooks 2006).

Establishing and maintaining habitat corridors within a matrix of human development has become an important goal of conservation biology. Roads are major impediments to animal movement, and therefore connectivity, in many corridors (Saunders et al. 1991, Kramer-Schadt et al. 2004). For some animals, roads represent barriers that they are unable or unwilling to cross (Coffin 2007). For those that do attempt to cross roads, collisions with vehicles can increase mortality dramatically (Forman and Alexander 1998). In these ways, roads can effectively fragment otherwise continuous habitat.

To mitigate some of the negative effects of roads, conservationists have advocated the construction of crossing structures such as overpasses and underpasses, specifically for wildlife use (Forman and Alexander 1998, Clevenger and Waltho 2000). Studies of activity and movements of medium and large mammals in the Puente-Chino Hills area of southern California revealed several areas where topography and high traffic volume restrict movements of wildlife (Haas 2000, Haas and Turschak 2002). It was recommended that underpasses be constructed to reduce mortality due to animal-vehicle collisions (roadkills). One of the recommended locations was on Harbor Boulevard, a divided, four-lane surface road that crosses the Puente Hills between the city of La Habra, Orange County and unincorporated Rowland Heights, Los Angeles County. Harbor Boulevard has a speed limit of 45-50 mph and traffic volume of >30,000 vehicles per day (County of Los Angeles 2007), and is a major north-south commuter route in the area. The Puente Hills Landfill Native Habitat Preservation Authority (hereafter, Habitat Authority), in association with Los Angeles County and California State Parks, proposed that a wildlife underpass be constructed beneath Harbor Boulevard. Construction began in September 2005, and the underpass was completed in late May 2006.

To determine the efficacy of the underpass, we monitored the activity of medium- and large-sized mammals in the vicinity of the underpass using a combination of roadkill surveys, track-station surveys and remote cameras. Our objectives were to:

1) establish and monitor patterns of activity of medium and large-sized mammals in the area near the site of the proposed underpass on Harbor Boulevard and throughout the western Puente Hills before, during and after construction of the underpass;

2) determine the frequency, spatial patterns, and species composition of wildlife found dead (roadkills) on major roads, including Harbor Boulevard, in the western Puente Hills before, during and after underpass construction;

3) monitor use of the completed underpass by wildlife.

METHODS

Study Area

The Puente Hills are part of the Puente-Chino Hills Wildlife Corridor, which is connected to the Santa Ana Mountains at Coal Canyon in Yorba Linda, Orange County, California. The main area of study consisted of the western section of the Puente Hills (Fig. 1), from Harbor Boulevard west to Workman Mill Road, on lands administered by the Habitat Authority and several major roads in the Puente Hills area (administered by Los Angeles County Public Works). The study area is primarily in southern Los Angeles County, California, with a small section of the roadkill route (see below) in northern Orange County.

Land use in the western Puente Hills is a patchwork of open space and rural and high-density housing, with limited retail and commercial use and gas/oil exploration. A landfill and a large cemetery are located at the western end of the Puente Hills. A large parcel of private land immediately east of the study area is primarily grassland and is leased for cattle grazing. The remaining open space is more-or-less connected and continuous, albeit surrounded by development, primarily housing tracts.

The dominant native vegetation type in the Puente Hills is coastal sage scrub, with stands of oak-walnut woodland in canyons. Non-native, invasive plants such as black mustard (*Brassica nigra*), fennel (*Foeniculum vulgare*), artichoke thistle (*Cynara carduncululus*) and non-native grasses are common in open areas. A number of native vegetation restoration projects are in progress.

The wildlife underpass was constructed at 33^{O} 57’ 26.92” N, 117^{O} 55’ 17.94” W on Harbor Boulevard, 300 m south of its intersection with Vantage Point Drive in the city of La Habra Heights, Los Angeles County, where Harbor Boulevard crosses the Puente Hills. The underpass was 5.2 m high, 6.1 m wide and 48.8 m in length, and was constructed of corrugated steel, with a dirt floor. For more information on the funding and construction of the underpass, see Gullo (2007). Data collection was planned around the construction of the underpass. Before, during and after construction sampling periods hereafter refer to the timing of construction of the underpass.

Roadkill Surveys

Major surface roads that dissect the study area were surveyed for roadkills from July 2004 to June 2007. Surveys were conducted by driving a route that included each of the major roads that cross the hills, and recording the location of any vertebrate animals observed dead on the road. The route included 37.8 km of surveyed roads (Fig. 2), which were, from west to east, Workman Mill Road (4.8 km), Turnbull Canyon Road (6.4 km), Colima Road (3.7 km), Hacienda Boulevard (4.8 km), Fullerton Road (2.7 km), and Harbor Boulevard (3.2 km). Other roads (12.2 km total) were also included to create a route connecting all the roads of interest, but were not included in analyses. Surveys were conducted on weekdays, starting at approximately 0530 hrs. Locations of road-killed animals were marked with a Garmin GPS Map 76S Global Positioning System unit (datum WGS 1984) and mapped using ESRI ArcGIS 9.0 mapping software (ESRI, 380 New York Street, Redlands, CA 92373, USA). The specific location of the animal on the road (e.g. east side, west side or center divider), and whether traffic was traveling uphill, downhill or more-or-less level at that location were also recorded. Animals were identified to species when possible. Scientific names for all species mentioned are in Table 1.

We surveyed the route a total of 140 times (approximately weekly) from 1 July 2004 to 2 July 2007: 53 times before underpass construction (1 July 2004 – 29 September 2005); 34 times during construction (4 October 2005 – 25 April 2006); and 53 times after construction (2 May 2006 – 2 July 2007).

Data on traffic volume for the main roads in the survey route (Workman Mill Road, Turnbull Canyon Road, Colima Road, Hacienda Boulevard, Fullerton Road, and Harbor Boulevard) were obtained from the Los Angeles County Public Works (LACPW) website (County of Los Angeles 2007). We used 24-h count data (number of vehicles per 24-h period) from traffic count machines to estimate and compare mean traffic volume across the survey route. These surveys used were conducted by LACPW between 23 January 2002 and 25 June 2007. Because the number of surveys varied greatly among roads (n = 3 for Turnbull Canyon Road, versus n = 67 for Colima Road), and because weekend traffic volumes were typically lower, we used only weekday counts to calculate mean 24-h counts for each road (Table 2). Traffic volume data were not available for the entire roadkill route, but all major roads of interest in the survey route were represented.

The posted speed limit on each section of road in the survey route was also recorded and incorporated into a geographic information systems (GIS) file (Fig. 3).

Track-Station Surveys

Track-station surveys were used to monitor activity of medium- and large-sized mammals in the study area. Track stations consisted of a circular 1-m^2 plot of gypsum powder sifted through a soil sieve (U.S.A. Standard Testing Sieve No. 18, mesh size 1.00 mm). A rock was placed in the middle of the plot and baited with a commercial scent lure (Russ Carman's Pro's Choice). Individual track stations were arranged into transects consisting of five track stations, spaced 200 m apart. Transects were placed on service roads throughout the study area, as well as on both shoulders of Harbor Boulevard to estimate activity levels near the construction area. Transects were grouped into four areas, from east to west, consisting of three or four transects each (Fig. 4). The sampling area in the vicinity of Harbor Boulevard (area A) at the east end of the study area had four transects, including those on the shoulders of Harbor Boulevard (Fig. 5). Area B included three transects in the area around Hacienda Boulevard and Colima Road (Fig. 4). Area C consisted of three transects in the area from Colima Road to just north of Turnbull Canyon Road. At the west end of the Puente Hills, area D included three transects in the area between Turnbull Canyon Road and Workman Mill Road. Transects in a given area were sampled together. A random number generator was used to determine the order (A, B, D, C) in which areas were sampled.

Track stations were operated for 3 consecutive nights during each sampling session. Track stations were set in the evening and checked the following morning. Tracks were identified to species when possible. During construction, some track stations on Harbor Boulevard were inaccessible and were not sampled. Three track stations were placed in the newly constructed underpass on Harbor Boulevard (one at each end, and one in the center) and sampled for five sessions from 18 June 2006 to 21 April 2007. During two of these sampling sessions, the west end of the tunnel was too wet to accommodate a track station, so only the east and center track stations were operated. Track stations in the underpass were not used in any statistical comparisons because they were not operated before or during construction. They were primarily used to document use of the underpass.

Counts from track-stations were used to calculate an index of relative activity, I_{jk}, for species k at transect j, following Haas (2000):

$$I_{jk} = [v_{jk}/(s_j n_j)]$$

where v_{jk} = number of stations visited by species k at transect j,

s_j = number of stations in transect j, i.e., 5,

n_j = number of nights that stations were active in transect j, i.e., usually 3.

Values of I_{jk} ranged from 0 for no activity to 1.0 for complete visitation.

Each set of transects was sampled twice before construction, twice during construction and twice after construction. Before construction, track-station surveys were conducted in spring (19 April – 15 June) and summer (11 July – 24 August) 2005. During construction, track-station surveys were conducted in fall (20 October – 13 December) 2005 and winter 2005 – 06 (28 December 2005 - 24 January 2006). After construction, track-station surveys were conducted from summer – fall (4 July – 26 October) 2006 and winter – spring (16 January– 29 March) 2007.

An additional track-station session was run from 2 April – 18 June 2007 with stations sampled for 5 consecutive nights. This allowed us to compare activity indices between 3-night and 5-night sampling periods. For all species detected, we calculated an index of activity from the 5-night sampling period and compared this with the index of activity calculated from the first three nights of the 5-night sampling period.

We estimated housing density in the vicinity of each track-station transect using an aerial photograph of the study area (taken December 2003) obtained from the Habitat Authority. The photo was incorporated into an ArcGIS file. We counted the number of residential housing structures within 500 m of each transect (an area of ~1.2-1.6 km^2, depending on the curvature of individual transects).

Remote-Camera Surveys

Remotely triggered infrared digital cameras (Leaf River Outdoor Products, Game Camera Model iR-3BU) were placed in the underpass once it was completed. On 26 May 2006, one camera was bolted at each end of the tunnel, at a height (~5 m) to discourage tampering. The cameras were moved about 1 m below their initial location to the side of the tunnel on 11 June 2006. A third camera was added in the middle of the tunnel on 3 September 2006. This camera was placed ~1 m off the ground to verify that higher cameras were not missing smaller mammals. The two cameras on either end of the tunnel were moved down to ~1 m off the ground on 13 February 2007. Cameras were operated until 30 June 2007. Although we occasionally photographed people, there was no obvious evidence of tampering.

Statistical Analyses

Because roadkill data consisted of counts with many zeros, surveys were combined into groups of five surveys. There were 11 groups of five surveys before and after construction, and six groups of five surveys during construction. Data were also adjusted for the differing lengths of roads. The resulting data were defined as the "roadkill index" (number of roadkills per km per five surveys). Domestic animals, reptiles, birds, rodents, and unidentified animals were excluded from all roadkill analyses, and some species were recorded too infrequently for meaningful statistical analysis. Opossums, striped skunks, raccoons, badgers, and gray foxes were grouped as 'small carnivores' and analyzed as a single unit. ANOVA was used to compare roadkill indices among sampling periods and roads for coyotes and small carnivores, and for all species combined. Because there were no obvious seasonal differences in patterns of roadkills were detected, season was not included in analyses. Data were not normal and transformations did not improve this; however, ANOVA is robust with regards to non-normality (Zar 1996). Tukey multiple comparisons tests were used to identify significant differences in roadkill indices among sampling periods.

We also compared roadkill indices from equivalent time spans before (July 2004 – June 2005; nine groups of five surveys) and after (July 2006 – June 2007; nine groups of five surveys) underpass construction on Harbor Boulevard, and on all other roads combined. Paired t-tests were used to compare roadkill indices between sampling periods for coyotes and small carnivores, and for all species collectively. We used X^2 tests to examine differences in the number of roadkills of coyotes and all species combined between the northbound (mostly uphill) and southbound (mostly downhill) lanes of Harbor Boulevard before and during construction, when no crossing structures were available, and after the underpass was completed.

To investigate seasonal differences in roadkills, surveys were combined into blocks representing the wet and dry seasons typical of California's Mediterranean climate. Roadkill indices were calculated for wet (November – March; 10 groups of five surveys) and dry (April – October; 18 groups of five surveys) seasons on Harbor Boulevard and on all other roads combined, pooling across sampling periods (before, during and after underpass construction). We used t-tests to compare roadkill indices between seasons for coyotes and small carnivores, and for all species collectively.

ANOVA or t-tests were used to compare traffic volume among roads and sampling periods. Some roads had multiple speed limits. For testing the effect of speed limit and road volume on frequency of roadkills, roads were broken into sections based on where posted speed limits changed. Mean roadkills per km was calculated for each section, combining across all surveys. These data more closely resembled a normal distribution. Log (base-10) transformation further improved normal-probability and residual plots. Correlation was used to examine relationships among posted speed limits, estimates of traffic volume and log-transformed roadkills per linear km. We also divided road sections into those with speed limits $\leq$40 mph or >40 mph, and used t-tests to compare log-transformed roadkills per km for coyotes and small carnivores, and for all species collectively, between sections with relatively high and low speed limits.

Nested ANOVA was used to compare track indices for each species among sampling periods and sampling areas, with transect nested within area. Following Sargeant (2003), a minimum detection rate of 0.10 was applied for track-station analysis; species detected below this rate were not included in analyses. Track-station data deviated somewhat from normality and were heteroscedastic. Data transformations did not alleviate this. However, because ANOVA is robust with regards to non-normality and homogeneity of variance (Zar 1996, McGuinness 2002), use of parametric ANOVA on the untransformed data was considered appropriate. Tukey multiple comparison tests were used to identify significant differences in track indices within treatments. To investigate seasonal effects on track-station indices, track-station surveys were grouped into seasonal blocks in the same manner as roadkill surveys (wet and dry seasons; n = 33 surveys for both seasons), pooling across sampling periods. Paired t-tests were used to compare track-station indices between wet and dry seasons for coyotes and striped skunks.

Paired t-tests were used to compare the 5-night and 3-night track station indices. Correlation was used to investigate relationships between housing density (buildings/km^2; square-root transformed) and track-station indices.

Rainfall data for the study period were obtained from the Western Regional Climate Center (Western Regional Climate Center, 2008). Average monthly rainfall totals were calculated from five weather stations located in the vicinity of the Puente Hills (Covina, Pomona, San Gabriel, and Whittier, Los Angeles County, and Yorba Linda, Orange County) from July 2004 – June 2007. Based on the distribution of precipitation across months for weather stations in the region (NOAA National Climatic Data Center 2008), we designated the months of November-March as the "wet" season (>85% of mean annual rainfall), and April to October as the "dry" season.

Map development and housing density estimates were done using ESRI ArcGIS 9.0 mapping software. All statistical tests were performed using SAS 9.1.

RESULTS

Roadkill Surveys

A total of 175 vertebrate animals were recorded dead on roads during 140 surveys (Table 3) between 1 July 2004 and 2 July 2007, an average (± 1 SE) of 1.3 ± 0.1 roadkills per survey. Striped skunks were recorded as roadkills most often (18%), followed by opossums (15%), rodents (13%) coyotes (12%), desert cottontails (8%), domestic animals (8%), raccoons (6%), birds (3%), mule deer (2%), and reptiles (2%). A gray fox was recorded once (<1%). On 26 July 2006, we found a badger dead on Colima Road, which was notable because badgers were not known to still be present in the Puente Hills (A. Henderson, Habitat Authority, *pers. comm.*). An additional 16 carcasses were unidentifiable (9%). Reptiles, birds, rodents, domestic animals, and unidentified animals were excluded from all analyses and hereafter are not included in any results. We observed 51 roadkills before construction (1.0 ± 0.1 roadkills per survey; $n = 53$), 37 roadkills during construction (1.1 ± 0.2 roadkills per survey; $n = 34$), and 39 roadkills after construction (0.7 ± 0.1 roadkills per survey; $n = 53$).

For coyotes (Fig. 6), roadkill indices varied significantly among roads ($F = 11.96$, $DF = 5$, $P < 0.0001$), but not among sampling periods ($F = 0.92$, $DF = 2$, $P = 0.3989$). Coyotes were found dead on only three of the roads surveyed (Harbor Boulevard, Colima Road, Workman Mill Road). Overall, the number of roadkills of coyotes was higher on Harbor Boulevard than on Colima Road or Workman Mill Road (Table 4). However, there was also a significant interaction between road and sampling period on the frequency of coyote roadkills ($F = 2.35$, $DF = 10$, $P = 0.0132$). The number of coyote roadkills on Colima Road was higher during construction than before or after, and during construction the number of coyote roadkills on Colima Road was higher than on Harbor Boulevard. The area near the intersection of Harbor Boulevard and south Fullerton Road had a cluster of coyote roadkills before, during and after construction (12 coyote in a 1.25 km section) that was not recorded anywhere else in the study area (Fig. 7). On Colima Road, roadkills of coyotes were fewer and sparser (Fig. 8). Only one coyote was recorded dead on Workman Mill Road (Fig. 9). Indices of coyote roadkills did not differ significantly among sampling periods on any road. Specifically, there was no decrease in the number of road-killed coyotes on Harbor Boulevard following underpass construction.

For small carnivores, roadkill indices (Fig. 10) varied significantly among roads ($F = 6.07$, $DF = 5$, $P < 0.0001$), but not among sampling periods ($F = 0.50$, $DF = 2$, $P = 0.6064$). There was no significant interaction between road and sampling period ($F = 0.76$, $DF = 10$, $P = 0.6623$). Roadkills of small carnivores were highest on Hacienda Boulevard and Harbor Boulevard, followed by Colima Road, Workman Mill Road and Turnbull Canyon Road (Table 4). No small carnivores were detected on Fullerton Road. No significant differences in small-carnivore roadkill indices were detected among sampling periods on any individual road, notably Harbor Boulevard.

For all species combined (Fig. 11), roadkill indices varied significantly among roads ($F = 14.12$, $DF = 5$, $P < 0.0001$), but not among sampling periods ($F = 1.92$, $DF = 2$, $P = 0.1509$). There was no significant interaction between road and sampling period ($F = 0.93$, $DF = 10$, $P = 0.5119$). Roadkills were highest on Harbor Boulevard, followed by Colima Road, Hacienda Boulevard, Workman Mill Road, Fullerton Road, and Turnbull Canyon Road (Table 4). There were also no differences in roadkill indices before, during and after construction on any road. Roadkills of combined species did not decline significantly on Harbor Boulevard after construction of the underpass.

On Harbor Boulevard and on all other roads combined, there were no significant differences between wet and dry seasons in the number of roadkills for coyotes, small carnivores or for all species combined ($P>0.2070$; Table 5).

To examine more closely changes in roadkills on Harbor Boulevard in response to the construction of the underpass, we first compared roadkill indices during the year

(July-June) prior to construction to the same months post-construction, to account for any confounding effects of season or time of the year. We found no significant differences between roadkill indices of coyotes, small carnivores or all species combined before vs. after construction ($P>0.1689$; Table 6). We also found no significant differences between sampling periods for roadkill indices of coyotes ($t = 1.51$, $DF = 8$, $P = 0.1690$) or small carnivores ($t = 0.54$, $DF = 8$, $P = 0.6072$) on all other roads combined, although the total number of roadkills (all species combined) on all other roads was significantly lower after construction than beforehand ($t = 2.35$, $DF = 8$, $P = 0.0470$; Table 6).

Second, we examined differences in the pattern of roadkills between the northbound and southbound lanes of Harbor Boulevard because we expected differences in both vehicle speeds and required braking distances for vehicles traveling uphill vs. downhill. For these comparisons, we assumed that animals were struck immediately upon entering the roadway, and in the lane in which their carcasses were found. Because we were interested in whether the completion of the underpass reduced at-surface crossings, we combined surveys conducted before and during construction, when no animals could use the tunnel. In general, more animals were struck in the southbound lanes (20) than in the northbound lanes (11). After construction, the number of road-killed coyotes in northbound lanes was lower than in southbound lanes, although the difference was not significant ($X^2 = 0.67$, d.f. = 1, $P = 0.414$; Fig. 12), in part because sample sizes were low. Combining all species, however, there were significantly fewer roadkills in the northbound after construction ($X^2 = 4.45$, d.f. = 1, $P = 0.035$; Fig. 12), but no difference before the underpass was completed ($X^2 = 0.20$, d.f. = 1, $P = 0.655$). Six species (7 coyotes, 4 opossums, 4 striped skunks, 2 bobcats, 2 desert cottontails, 1 raccoon; n = 87 surveys) were killed before and during construction, compared to only four afterward (6 coyotes, 2 opossums, 2 striped skunks, 1 raccoon; n = 53 surveys).

Mean (± SE) 24-h traffic volumes (data from LACPW; Table 2) were highest on Colima Road (39,292 ± 323 vehicles), followed by Harbor Boulevard (33,270 ± 484 vehicles), Workman Mill Road (26,498 ± 1,396 vehicles), Hacienda Boulevard (20,809 ± 872 vehicles), Turnbull Canyon Road (1,403 ± 457 vehicles), and Fullerton Road (1,314 ± 65 vehicles). Only Colima Road had a sufficiently large sample size of traffic volume data (n = 67 surveys) for meaningful analysis, however these data were skewed with regards to sampling period (before construction, n = 52; during construction, n = 11; after construction, n = 4). Traffic volume data on Harbor Boulevard were analyzed despite sample size being small and unbalanced (before and during construction, n = 8 and 4 surveys, respectively) because of the central role of Harbor Boulevard in this study. On Colima Road, mean 24-h traffic counts increased slightly during construction (4%), but not significantly (F = 2.05, DF = 2, P = 0.1367; Table 7). Mean 24-h traffic counts on Harbor Boulevard also did not differ significantly (t = -0.61, DF = 10, P = 0.5577; data were not available post-construction). Traffic volume data from other roads were not included in comparisons because of small sample sizes.

Combining all sampling periods, posted speed limit was not significantly related to the number of roadkills per km (r = 0.44, P = 0.1569; Fig. 13a). Traffic volume was positively related to the number of roadkills per km (r = 0.74, P = 0.0061; Fig. 13b). Posted speed limit and traffic volume, however, were correlated (r = 0.66, P = 0.0206). Roads with higher posted speed limits (>40 mph) tended to have higher frequencies of roadkills than those with lower speed limits (≤40 mph), but the difference was marginally non-significant ($t = 2.02$, $DF = 10$, $P = 0.0710$).

Track-Station Surveys

Track-station surveys conducted from April 2005 through June 2007 resulted in 1,673 unique tracks (hits; Table 8). Of 1,706 station-nights, 1,313 (77%) had at least one track. Most (68%) track-station hits were coyotes, followed by striped skunks (12%), desert cottontails (6%), rodents (5%; not identified to species), domestic dogs (3%), and mule deer (2%). Small fractions (<1% each) were gray foxes, long-tailed weasels, bobcats, raccoons, and opossums. Very few (<1%) were unidentifiable. On 30 December 2005 we recorded an unknown track that was photographed and later identified as the hind-foot of a badger. The two track-station transects on the shoulders of Harbor Boulevard (area A) produced artificially low track indices, presumably due to their close proximity to traffic. These transects were excluded from analyses.

Only coyotes and striped skunks were detected at a high enough rate (≥ 0.10) for statistical analyses. Track indices of coyotes (Fig. 14) varied significantly among areas ($F = 3.76$, $DF = 3$, $P = 0.0361$), but not among sampling periods ($F = 2.43$, $DF = 2$, $P = 0.1238$). Track indices of coyotes were highest in area A, followed by areas C and D, which were similar (Table 9). Indices were lowest in area B. There was no significant interaction between sampling period and area ($F = 0.34$, $DF = 6$, $P = 0.9022$). Similarly, track indices of striped skunks (Fig. 15) varied significantly among areas ($F = 5.17$, $DF = 3$, $P = 0.0129$), but not among sampling periods ($F = 0.36$, $DF = 2$, $P = 0.7069$). There was no significant interaction between sampling period and area ($F = 0.55$, $DF = 6$, $P = 0.7638$). Striped skunks were detected most often in areas B and D (Table 9), and overall, were detected less often than coyotes. We found no seasonal differences in activity indices of either coyotes ($t = -1.36$, $DF = 32$, $P = 0.1839$) or striped skunks ($t = 0.77$, $DF = 32$, $P = 0.4481$; Table 10).

Track indices of both coyotes and striped skunks were significantly related to housing density (Fig. 16). Track indices of coyotes were negatively related to housing density ($r = -0.33$, $P = 0.0067$), whereas indices of striped skunks were positively related to housing density ($r = 0.43$, $P = 0.0004$).

Track indices calculated from the 5-night sampling session were compared with track indices calculated from the first 3 nights of the 5-night sampling period for each species detected. Only striped skunks differed significantly ($t = -2.28$, $DF = 15$, $P = 0.0375$), with a higher detection rate for the 3-night period (Table 11). Pooling across the entire study area, no species were detected on sampling night 4 or 5 that were not detected in the first 3 sampling nights.

Track stations inside the Harbor Boulevard underpass recorded tracks of coyotes, bobcats, mule deer, and rodents. Of 51 station-nights, 40 had coyote tracks, 21 had rodent tracks, 2 had mule deer tracks, and 1 had bobcat tracks. The number of rodent tracks was relatively high because at least one mouse took residence in the middle of the tunnel. Anecdotally, we also observed tracks of northern raccoons and striped skunks in mud in the underpass, but not in track stations.

Remote-Camera Surveys

Remote cameras first recorded deer and coyotes in the Harbor Boulevard underpass three and four weeks after installation, respectively (Fig. 17). Coyotes used the underpass fairly regularly. The average (± SE) detection rate of coyotes was 30.3 ±

5.7 photos per month, with a sharp increase observed in October 2006, 23 weeks after cameras were installed. Prior to the increase in October 2006, coyotes were detected at a rate of 6.0 ± 1.8 photos per month. After the increase, coyotes were detected at a rate of 43.8 ± 4.1 photos per month. Mule deer used the underpass less consistently, with an average detection rate of 4.7 ± 1.7 photos per month. Bobcats were photographed four times, once in February 2007 and three times in April 2007. Desert cottontails were photographed three times in June 2007. One striped skunk was photographed in June 2007, and one domestic dog was photographed in April 2007.

DISCUSSION

Roadkill Surveys

The most notable findings from our roadkill surveys were the high number of roadkills on Harbor Boulevard, especially coyotes, and the lack of any apparent difference in frequency of roadkills before, during and after construction of the underpass. In general, the high numbers of roadkills on Harbor Boulevard may, in part, be explained by the narrowness of the habitat corridor in this area of the Puente Hills, which is constricted by high-density housing development and likely concentrates the movement of animals into a narrow area. This confirmed the need for mitigating measures such as construction of the new wildlife underpass on Harbor Boulevard, which were largely absent prior to its construction. Deer-crossing warning signs were already in place on Harbor Boulevard, but such passive, permanent signs are thought to be largely ineffective at reducing vehicle-wildlife collisions (Pojar et al. 1975, Putman 1997, Sullivan and Messmer 2003). An existing equestrian tunnel under Harbor Boulevard near its intersection with Pathfinder Road (approximately 1.2 km north of the new underpass) is not heavily used by wildlife, especially larger animals (Haas 2000; A. Henderson, Habitat Authority, *pers. comm*.; D. Elliott, *pers. obs*.). The equestrian tunnel is closer (<100 m) to high-density housing, and does not connect directly with native habitat on either side.

The area on Harbor Boulevard near its southern intersection with Fullerton Road appeared to be a major movement route for coyotes, as many were killed there (Fig. 7), even after the underpass was completed. The local topography may dictate that this area is a more suitable crossing point, from the animals' perspective, than farther north where the tunnel was eventually built. At the location of the underpass, Harbor Boulevard cuts through the end of a small east-west oriented canyon, and the road was constructed on fill dirt, which obstructs the western end of the canyon. This fill creates a steep grade from the east end of the underpass down to the canyon floor. At its southern intersection with Fullerton Road, the surface of Harbor Boulevard is closer to the natural, pre-fill elevation. Based on the presence of heavily used trails below the shoulder on the east side, animals attempting to cross Harbor Boulevard might be naturally funneled south to its intersection with Fullerton Road. Interestingly, we found a decrease in the number of total roadkills, and, to a lesser extent, coyotes, in the uphill, northbound lanes of Harbor Boulevard after construction, which suggests that animals moving from east to west now use the underpass more than surface crossings. The number of roadkills actually was higher in the southbound lanes post-construction; if animals are struck immediately upon entering the road, this pattern suggests that animals moving from west to east have not found or do not regularly use the underpass, choosing instead to cross farther south. We speculate that faster vehicle speeds of downhill traffic may also contribute to the higher numbers of roadkills in those lanes.

Overall, the lack of a significant reduction in roadkills following the completion of the underpass raises some questions about the effectiveness of the new underpass in reducing roadkills on Harbor Boulevard. One possible explanation is that our study did not encompass a long enough time period after construction to document a decrease in the number of roadkills. Resident individuals or their offspring born before the underpass was complete may have continued to cross at other, more familiar points, which could explain the relatively high frequency of roadkills, especially coyotes, after construction. Additional measures, discussed below, may be needed to increase the use of the underpass by wildlife, discourage wildlife from crossing Harbor Boulevard at the surface, or reduce opportunities for wildlife-vehicle collisions on this road.

Of all the roads surveyed, Harbor Boulevard and Colima Road had the highest frequency of roadkills. All but one of the coyote roadkills was recorded on Harbor Boulevard and Colima Road, and the two dead bobcats spotted were both on Harbor Boulevard. Only four deer were recorded as roadkill, but all were on Colima Road. Both roads had high posted speed limits (≥ 45 mph) and relatively high daily traffic volumes (> 30,000 vehicles per day on average), and cross considerable amounts of open space.

Workman Mill Road had relatively few roadkills considering that it had a speed limit of 45 mph and an average daily traffic volume >26,000 vehicles. Workman Mill Road is at the western terminus of the Puente Hills, and there is little available habitat adjacent to it or immediately to the west. The San Gabriel River is ~1 km west of the road; however, movement between the Puente Hills and the San Gabriel River is probably minimal, especially considering that Route 605, a divided eight-lane freeway, and several industrial complexes separate the two. Workman Mill Road is bordered on the east largely by a fenced cemetery and residential housing, creating an unnatural buffer between native habitat and the road that probably restricts road crossings to the west.

In contrast, Hacienda Boulevard, which had a posted speed limit of 35 mph for most of the surveyed stretch, had a relatively high number of roadkills. Hacienda Boulevard is also fairly heavily traveled (> 20,000 vehicles / day), especially for a two-lane road. Anecdotally, we noticed that many drivers tended to exceed posted speed limits on Hacienda Boulevard. Hacienda Boulevard is primarily bordered by low-density housing along the southern stretch where most of the roadkills occurred. Most roadkills on Hacienda Boulevard were species that are often found in association with human development, such as opossums, striped skunks and rats (Ingles 1965, Kays and Wilson 2002).

Other factors may account for spatial variation in roadkill patterns. For example, Turnbull Canyon Road had the fewest roadkills per km. It is one of the least traveled roads in the study area (~1,400 vehicles / day) and is quite curvy, which may force drivers to slow down and be more alert. Further, ravens were often seen perching on power lines above the western stretch of Turnbull Canyon Road, and were once observed scavenging on a roadkill carcass. Ravens and other scavengers may have removed some roadkills, especially smaller animals, before the roads were surveyed. The low traffic volume here may have further facilitated scavenging.

Higher vehicle speeds and traffic volume are known to be associated with higher frequency of wildlife-vehicle collisions (Rolley and Lehman 1992, Romin and Bissonette

1996, Inbar and Mayer 1999, Saeki and Macdonald 2004, Dussault et al. 2006). Likewise, in our study, roadkills also tended to be recorded more frequently on roads with higher posted speed limits and especially, higher traffic volumes, although other factors such as the locations of natural movement routes or local topography may also be important.

The increase in coyote roadkills on Colima Road during construction remains unexplained. We initially hypothesized that traffic volume on Colima Road might increase during the construction of the Harbor Boulevard underpass, which could increase roadkills. Traffic was often slow and congested on Harbor Boulevard during construction, and for some commuters who normally traverse Harbor Boulevard, Colima Road may have been a logical detour. However, the available traffic count data on Colima Road suggest that, although the mean traffic count increased slightly during construction (1,677 cars, a 4% increase; Table 5), mean traffic counts did not vary significantly among sampling periods. Also, construction did not reduce traffic volume on Harbor Boulevard compared to before construction (no data were available after construction). If the increase in coyote roadkills on Colima Road was influenced by underpass construction, some factor, perhaps related with human activities elsewhere, weather or the biology of coyotes, other than traffic volume may have been involved.

Comparing the year before and the year after construction, the only significant difference in roadkills we detected was for all species combined, on roads other than Harbor Boulevard. Given that some of these roads were quite far from the underpass, and that we found no differences on Harbor Boulevard itself, it seems unlikely that this decrease could be attributed to the construction of the underpass. Although we did not find any seasonal differences in roadkill indices, we note that rainfall in the 2004-05 wet season, prior to construction, was much higher than during the post-construction sampling period in 2006-07 (Fig. 18). One possible explanation is that population densities of some species, particularly smaller carnivores, were regionally higher following a period of high resource productivity, resulting in more crossing events and higher numbers of vehicle collisions. Similarly, driving conditions during this period may have been poorer, leading to an increase in accidents overall.

Track-Station Surveys

At least 12 species were detected at track stations in the western Puente Hills (Table 3), which was comparable to studies in similar habitats in southern California (Crooks 2002, Lyren et al. 2006). Only two species (coyote and striped skunk) were detected often enough ($I_{jk} \geq 0.10$) for statistical analyses. It has been suggested that a moderate detection rate (I_{jk} = 0.4-0.6) at track stations is ideal for detecting differences (Roughton and Sweeny 1982). Coyotes were usually detected at rates higher than this across the study area. The overall average detection rate of coyotes was 0.77, with only 18% of surveys resulting in a detection rate <0.60. It is possible that the high levels of activity of coyotes in the western Puente Hills may obscure detection of further spatial or temporal differences. Other factors not included in this study probably also influence distribution and activity patterns of coyotes and other species in the Puente Hills. For example, the activity or distribution of carnivores can be influenced by vegetation (Cain et al. 2003) and human recreational activities (George and Crooks 2006), as well as roads (Riley 2006).

Coyotes were detected at relatively high rates compared to similar, but less fragmented, habitat. Lyren et al. (2006), for example, reported a detection rate of 18.3% for coyotes in nearby Irvine Ranch, in Orange County. Although track stations cannot be used to estimate population size or density (Sargeant et al. 1998, 2003), the high levels of activity at track stations suggest that coyotes occur at relatively high densities in the western Puente Hills. This may, in part, be due to human food subsidies that were abundant in the form of garbage, pets, pet food, and fruit from ornamental plantings (Fedriani et al. 2001). The cemetery at the western end of the Puente Hills may also provide enhanced food sources for coyotes. Aggregated resources such as anthropogenic food sources can increase group size of coyotes (Atwood 2006), and the peninsular nature of the habitat may have reduced dispersal of young, further concentrating their numbers. Atwood et al. (2004) found that coyote home-range size in Indiana was inversely related to human development and road densities. Home ranges of coyotes may be smaller in the western Puente Hills than in similar habitat farther from human development, resulting in higher population densities. Coyotes may also experience ecological release because of the scarcity of larger predators (Crooks and Soule 1999). Mountain lions (*Puma concolor*) have been occasionally reported in the western Puente Hills (A. Henderson, Habitat Authority, *pers. comm.*), but are probably rare and transitory due to their large space requirements. High densities of coyotes in the western Puente Hills may also help explain the low visitation rates of smaller carnivores observed in this study, whose populations may be limited by coyote predation (Crooks and Soule 1999).

Coyotes were detected least often in area B, an area that encompasses part of the Puente Hills where the habitat corridor is particularly narrow and constricted by housing development (Figs. 1 and 4). Coyote detection rates were inversely correlated with housing density, which suggests that coyotes may tend to avoid human development, even though it may be a source of food. Native plant restoration projects were ongoing in area B during the study period. Habitat disturbance and increased human activity associated with these projects may have contributed to the low visitation rates of coyotes in this area. Coyotes in fragmented landscapes tend to spend less time in areas closer to human development and activity (Crooks 2002, Riley et al. 2003, Atwood et al. 2004, George and Crooks 2006). However, coyotes likely travel regularly through constricted points in the Puente Hills, e.g. area B, and possibly take advantage of human food subsidies, but may not linger, resulting in lower detection rates at track stations.

Striped skunks were detected less often than coyotes, and with greater spatial variability. The overall average detection rate of striped skunks was 15%, which was higher, but comparable to similar, but less fragmented habitat in the region (7.6% detection rate for striped skunks in Irvine Ranch; Lyren et al. 2006). Unlike coyotes, indices of striped skunk activity were highest in areas B and D, which have less open space than the other areas. Habitat is constricted in both B and D, and housing density was high, especially in area D. Striped skunks probably take advantage of anthropogenic food sources, resulting in higher numbers closer to housing developments, as suggested by the positive relationship between skunk activity and housing density. The cemetery at the western end of the Puente Hills may also provide habitat for skunks. Striped skunks are commonly found in urban/suburban settings, although research on the effects of human development and habitat fragmentation on striped skunks is equivocal. Some studies have found that striped skunks are common around human development (Rosatte et al. 1991, Prange and Gehrt 2004), while others suggest the opposite (Caro et al. 2000, Crooks 2002, Neiswenter and Dowler 2007). Our results suggest that striped skunks may benefit from proximity to human development in the western Puente Hills, at least along the edge of development and open space, if not within the urban matrix.

We also monitored track stations in the area of the Harbor Boulevard underpass to determine if construction influenced activity of wildlife, including coyotes and striped skunks. We found no differences in activity of coyotes or striped skunks that could be attributed to construction of the underpass. This was not surprising because disturbances due to construction, although intensive, were probably localized. Changes in activity at track stations would have been most evident on the shoulders of Harbor Boulevard. These stations had very low detection rates for coyotes and no visits by striped skunks, presumably because of their close proximity to fast-moving traffic. Construction did not appear to deter individuals from crossing Harbor at the surface because the frequency of roadkills did not change during construction.

Our documentation of the presence of badgers, considered a Species of Special Concern by the California Department of Fish and Game, was noteworthy because this species was not known to still reside in the Puente Hills. Unfortunately, because only one track and one road-killed specimen were recorded, our study cannot provide information on the density, status or viability of the badger population in the Puente Hills. Furthermore, because the road-killed badger was observed after the track was detected, it is possible that only a single individual was actually present, and that that individual was killed. Nonetheless, additional surveys for badgers might reveal a larger population than was previously known.

For most of our sampling efforts, track stations were monitored for 3 consecutive nights. A longer sampling period for track stations (i.e. more consecutive nights per session) has been suggested to be superior at detecting rare or more secretive species (L. Lyren, U.S. Geological Survey, *in litt.*), and recent studies of carnivore activity in southern California have used 5-night surveys (Crooks and Soule 1999, Haas 2000, Crooks 2002, Haas and Turschak 2002, Lyren et al. 2006). Shorter sampling periods may be sufficient to calculate activity of relatively common species and may be more precise because they reduce the effect of multiple visits by the same individual (Sargeant et al. 2003). Activity indices calculated from relatively low detection rates (< 0.10) are not regarded as particularly useful except to detect presence or absence (Sargeant et al. 1998). Roughton and Sweeny (1982) found that, for coyotes in California, no additional information was gained by operating track stations for more than 1 night. Individual track stations within a transect cannot be considered independent, as it is likely that individuals will visit multiple stations. Likewise, multiple nights in a sampling session cannot be treated as independent because it is likely that individual animals will return to a station on multiple nights. Therefore, given logistical constraints and the need to cover a sufficiently large geographical area, sampling the fewest number of stations per transect for the fewest number of nights can increase precision. Sample size can then be increased by maximizing geographic coverage of transects (spaced far enough apart such that independence can be assumed) and conducting multiple sampling sessions per year.

Based on sampling in spring 2007, we found little difference in visitation rates from a 3-night sampling period compared to a 5-night sampling period. Detection rates of striped skunks differed significantly, but were higher in the 3-night period. Moreover, there were no differences in the number of species detected between 3-night and 5-night sampling periods. In total, our sampling effort was intensive (>1,700 track-station nights) and extended over most of the western Puente Hills, with very high detection rates for species that were expected to be abundant. We also recorded the presence of those species known to be in the area that would visit scent-baited stations, and provided evidence of the presence of badgers, a species that previously was not known to be present locally.

Remote-Camera Surveys

Remote-camera surveys at the Harbor Boulevard underpass showed fairly consistent, high and possibly increasing use by wildlife, especially coyotes. It was particularly promising that mule deer used the underpass so soon after its completion because deer have been found to be reluctant to use underpasses (Reed et al. 1975, Ward 1982, Yanes et al. 1995) and generally require a period of adjustment to become accustomed to them (Putman 1997). Interestingly, deer were never found as roadkills on Harbor Boulevard. Although bobcats were only photographed three times, they were recorded toward the latter part of the study period, suggesting that resident individuals had learned of the location of the underpass. The use of the underpass by bobcats is a potentially important finding, as they are a potential target species for conservation efforts, and a previous study documented no movement of bobcats across Harbor Boulevard (Haas and Crooks 1999). Striped skunks and desert cottontails were similarly detected toward the end of the monitoring period, also suggesting that use by these species may have been increasing. As the plantings near the openings to the underpass mature, animals may become less wary of the tunnel and its use may increase.

Cameras and track stations were effective in documenting the timing of use of the underpass and the type of wildlife that used it frequently. However, it is likely that other animals were not detected. There were a large number of images with no animals in them; some of these presumably were triggered by wind. Also, a bird (black phoebe *Sayornis nigricans*) regularly perched on one of camera, and occasionally triggered it. In some cases, animals likely triggered a camera, but moved through the frame of view before the image was taken, because a number of images showed only the hindquarters of an animal. In addition, raccoon tracks were observed in mud in the tunnel on several occasions, but raccoons were never photographed, nor were they recorded in the track stations in the underpass. One set of bobcat tracks was observed in the underpass prior to the first photograph of a bobcat. Nonetheless, the combination of track stations and cameras clearly demonstrated that the new underpass is used often by wildlife.

CONCLUSIONS AND RECOMMENDATIONS

We strongly recommend continued monitoring of the Harbor Boulevard underpass to document its possible use by other wildlife species, and to detect changes in its use over time, especially as the plantings at the entrances mature. A pair of digital remote cameras, placed near ground level and checked weekly or bi-weekly, could accomplish this. Alternatively, a video monitoring system may be used for real-time monitoring that would not depend on triggering of remote cameras. We also recommend ongoing monitoring of roadkills along Harbor Boulevard to determine if frequency of roadkills, especially coyotes, decreases over time. Of particular concern is the area near the intersection with south Fullerton Road, where many coyotes were killed after construction. At a minimum, we recommend 1 year of additional monitoring of roadkills and underpass use. Additional monitoring that showed a decline in roadkills could suggest that most mortalities were individuals that were not familiar with the underpass.

If roadkills do not decrease, additional mitigation measures may be necessary on Harbor Boulevard. For example, plantings along the road should be low, with little or no cover, to prevent most carnivores from perceiving the road margins as attractive habitat. Cain et al. (2003) found that, in southern Texas, vehicles killed more bobcats on sections of road that were adjacent to preferred vegetation. Keeping vegetation cut back from Harbor Boulevard and other roads, where possible, may decrease the time animals spend near most areas of the road, in addition to being required for fire abatement.

Conversely, as vegetation planted at the entrances of the underpass matures, use of the underpass by wildlife may increase. Habitat enhancement on either side of the underpass, such as native plant restoration projects, in addition to the current native plantings, may further increase its use by wildlife. Increased vegetative cover near crossing structures has been positively linked with their use by wildlife (Putman 1997, McDonald and St Clair 2004, Ng et al. 2004).

Our results suggested that traffic speed may influence the frequency of roadkills. Reducing the posted speed limit on Harbor Boulevard should be considered, although the effects of speed limit reduction on frequency of roadkills has not been well studied (Knapp et al. 2004) and may be limited (Donaldson 2006, Huijser et al. 2007). Traffic calming measures such as flashing lights or rumble strips are also options, especially in the southbound lanes. Although such measures have not been well studied (Knapp et al. 2004, Donaldson 2006), they may be effective at reducing vehicle speed (Huijser et al.

2007), provided that human safety is taken into account. Ultimately, the addition of a traffic light at the intersection of Harbor Boulevard and south Fullerton Road would reduce traffic speed in the area where most roadkills occurred.

If high numbers of roadkills continue on Harbor Boulevard after other measures have been taken, fencing may be needed, especially in the area between the new underpass and Fullerton Road. Inspection of the road margin and adjacent slope on the east side of Harbor Boulevard revealed several well-used wildlife trails, consistent with frequent crossings in this area. If installed and maintained properly, fencing has been shown to prevent wildlife from accessing roads, decreasing roadkills (Falk et al. 1978, Ludwig and Bremicker 1983, Feldhamer et al. 1986). Any fence should be placed off the immediate shoulder and include escape ramps, especially on the east side of Harbor Boulevard near south Fullerton Road, where animals may enter Harbor Boulevard by traveling along Fullerton Road. Escape ramps allow animals that become trapped on the road to escape and reduce roadkills (Bissonette and Hammer 2000, Clevenger et al. 2002). We note that the original plan for the Harbor Boulevard underpass project originally included fencing along both shoulders in the vicinity of the underpass. We are concerned, however, that, fencing both sides of Harbor Boulevard over what would effectively be the entire width of the habitat corridor at its narrowest point may have unforeseen consequences for wildlife movement and overall connectivity (e.g., Jaeger and Fahrig 2004), perhaps to an even greater extent than that currently caused by vehicle-related mortality.

Alternative measures such as wildlife reflectors and active monitoring/warning systems would probably not work well on Harbor Boulevard. D'Angelo et al. (2006)

found wildlife warning reflectors ineffective at changing behavior of white-tailed deer (*Odocoileus virginianus*) near roads in Georgia. Ramp and Croft (2006) found that Swareflex and Strieter-Lite wildlife warning reflectors elicited little to no aversive responses in captive kangaroos in Australia. The steep topography in the area of Harbor Boulevard would probably make this type of system ineffective. Pojar et al. (1975) found a lighted, animated (but passive, i.e. does not change with the presence or absence of animals) deer warning sign did not reduce vehicle speed enough to effectively reduce the risk of deer being struck by a vehicle. Gordon et al. (2004) found the FLASH deer warning system did not reduce vehicle speeds enough to decrease deer-vehicle collisions in Wyoming. This system would likely be ineffective in the Puente Hills given the high number of vehicles and the infrequency with which the average motorist encounters wildlife on roads. The local topography would likely present unique challenges to the installation of this product as well. Further, this system was designed for preventing vehicle collisions with large mammals, whereas most of the roadkills observed in the Puente Hills were small to medium-sized carnivores, with relatively few deer, and none on Harbor Boulevard.

We also recommend that additional mitigation measures be considered on Colima Road, where there also were relatively high numbers of roadkills. The existing service tunnel under Colima Road was constructed for use by service vehicles, but it is used by hikers and bicyclists regularly, as well as by wildlife (Haas 2000, Haas and Turschak 2002, D. Elliott, *pers. obs.*). The existing equestrian tunnel on Colima Road also receives some use by wildlife, although less than the service tunnel (Haas 2000, D. Elliott, *pers. obs.*). We found substantial numbers of roadkills south of the service tunnel, and north of the crest, in the vicinity of the equestrian tunnel. Improvements such as increased native vegetation at the entrances and a dirt floor may make these existing structures more attractive to wildlife. Unfortunately, roadkills on Colima Road were not sufficiently clustered to suggest an exact location where new crossing structures might be considered. There were, however, a considerable number of roadkills on the stretch of road from the existing service tunnel north to the crest of the hill (approximately 33^{O} 58' 21.9" N 117^{O} 59' 19.33" W; Fig. 8). There are several small ravines along this stretch that might be suitable for an underpass.

Hacienda Boulevard also had high numbers of roadkills, most of which occurred south of the intersection with Skyline Drive; however, they were not sufficiently clustered to allow us to identify where additional mitigation measures might be particularly effective. Enhancements of drainage culverts on Hacienda Boulevard to increase their attractiveness to wildlife may be considered, especially since roadkills here were primarily smaller species. Improvements to the equestrian tunnel north of the intersection with Skyline Drive are not likely to be effective, given that few roadkills were recorded nearby. Other issues such as topography and land ownership may complicate efforts to implement mitigation measures on Hacienda Boulevard.

In summary, our roadkill and track-station surveys revealed high levels of wildlife activity in the western Puente Hills, suggesting high population densities of some carnivores such as coyotes and striped skunks. Given the limitations of track station surveys discussed above, different approaches may be needed to provide information on populations of rarer carnivores, such as foxes, weasels and badgers. Our roadkill surveys provided support for the decision to implement measures to reduce vehicle mortality on

Harbor Boulevard, including construction of the underpass; this area consistently had the highest concentrations of roadkills, especially coyotes. Our camera surveys demonstrated that the new underpass was quickly and regularly used by both deer and coyotes. Although the number of roadkills remained frustratingly high after construction, especially in southbound lanes, additional monitoring of use of the underpass and roadkills on Harbor Boulevard might reveal that the surviving individuals, as well as any new animals, have now learned to cross using the underpass. If roadkills do not decrease, however, additional traffic calming measures should be implemented (and their effectiveness monitored) before fencing of both sides of the road is considered.

Our study underscores the substantial amount of movement that occurs across roads that bisect natural areas of the western Puente Hills, which often result in considerable wildlife mortality. No information is available on the effect of this mortality on population dynamics of carnivores or deer in the Puente Hills, or the region as a whole. Wildlife movement through the Puente Hills is constricted by residential, transportation and industrial development on three sides. Near Harbor Boulevard, the remaining open space is particularly narrow (<1 km), which likely funnels animals into a relatively small area as they move through across the Puente Hills. Given the large space requirements of some species, the area near Harbor Boulevard is likely an important travel corridor that could be critical for maintaining connectivity of the western Puente Hills with other open space to the east, e.g. Chino Hills State Park. Additional studies of movement of wildlife species between the Harbor Boulevard area and these areas are needed to evaluate the consequences of new development that would further isolate wildlife populations in the western Puente Hills.

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TABLES AND FIGURES

Table 1. Scientific names of species observed during this study, following Stebbins (1985), Sibley (2000), and Kays and Wilson (2002). *Denotes species not native to California and domestic species.

Common name	Scientific name
gopher snake	*Pituophis melanoleucus*
western rattlesnake	*Crotalus viridis*
ring-necked pheasant*	*Phasianus colchicus*
American crow	*Corvus brachyrhynchos*
Virginia opossum*	*Didelphis virginiana*
coyote	*Canis latrans*
gray fox	*Urocyon cinereoargenteus*
northern raccoon	*Procyon lotor*
striped skunk	*Mephitis mephitis*
long-tailed weasel	*Mustela frenata*
American badger	*Taxidea taxus*
bobcat	*Lynx rufus*
mule deer	*Odocoileus hemionus*
desert cottontail	*Sylvilagus audubonii*
California ground squirrel	*Spermophilus beecheyi*
western gray squirrel	*Sciurus griseus*
eastern fox squirrel*	*Sciurus niger*
black rat*	*Rattus rattus*

domestic dog*	*Canis familiaris*
domestic cat*	*Felis domesticus*
domestic rabbit*	*Oryctolagus cuniculus*

Table 2. Mean traffic volume (24-h count) of roads, arranged from west to east in the roadkill survey route. Weekends were excluded because of large differences in the number of surveys available for each road (n). Data were obtained from the County of Los Angeles, Department of Public Works website (*accessed 1 August 2007*).

Road	Roadkill survey length (km)	Mean vehicles / 24 h	SD	n	Timing of surveys
Workman Mill Rd	4.8	26,498	3,418	6	28 Mar 2002 - 9 May 2006
Turnbull Canyon Rd	6.4	1,403	792	3	2 Apr 2002 - 27 Jun 2006
Colima Rd	3.7	39,292	2.648	67	23 Jan 2002 - 25 Jun 2007
Hacienda Blvd	4.8	20,809	2,657	9	30 Mar 2004 - 30 Mar 2007
Fullerton Rd	2.7	1,314	206	10	6 Jan 2004 - 12 Jan 2004
Harbor Blvd	3.2	33,270	1,675	12	4 Aug 2003 - 31 Mar 2006

Table 3. List of all animals recorded as roadkills from July 2004 through June 2007. Note that 16 roadkills, marked as unknown, were unidentifiable because of the condition of the carcass. Roadkills of unknown and domestic animals were not included in analyses. *Denotes domestic animals.

Common name	Number of roadkills
striped skunk	32
Virginia opossum	27
coyote	21
desert cottontail	14
California ground squirrel	11
northern raccoon	10
*domestic dog	7
*domestic cat	6
American crow	5
eastern fox squirrel	5
black rat	5
mule deer	4
western rattlesnake	3
bobcat	2
western gray squirrel	2
American badger	1
*domestic rabbit	1

gopher snake	1
gray fox	1
ring-necked pheasant	1
unknown	16
TOTAL	175

Table 4. Results of Tukey multiple comparisons tests for differences in roadkills per km among roads for coyotes, small carnivores and all species combined. For each species group, means with the same Tukey grouping letter are not significantly different. For all roads, sample size was 28 groups of five surveys.

Species	Road	Mean	SE	Tukey grouping
Coyotes	Harbor Blvd	0.15	0.03	A
	Colima Rd	0.07	0.03	B
	Workman Mill Rd	0.01	0.01	B
	Hacienda Blvd	0	0	B
	Turnbull Canyon Rd	0	0	B
	Fullerton Rd	0	0	B
Small carnivores	Harbor Blvd	0.16	0.03	A
	Hacienda Blvd	0.16	0.04	A
	Colima Rd	0.1	0.03	AB
	Workman Mill Rd	0.09	0.03	AB
	Turnbull Canyon Rd	0.01	0.00	B
	Fullerton Rd	0	0	B
All species combined	Harbor Blvd	0.36	0.06	A
	Colima Rd	0.29	0.04	AB
	Hacienda Blvd	0.22	0.05	AB
	Workman Mill Rd	0.15	0.03	BC
	Fullerton Rd	0.03	0.02	C
	Turnbull Canyon Rd	0.02	0.01	C

Table 5. Mean roadkill indices (roadkills per km per five surveys) for coyotes, small carnivores, and all species combined during wet (November - March) and dry (April - October) seasons. For wet and dry seasons, n = 10 and 18 groups of five surveys, respectively.

Species/Location	Wet season		Dry season	
	Mean	SE	Mean	SE
Coyotes				
Harbor Blvd	0.19	0.07	0.12	0.04
All other roads	0.02	0.01	0.01	0.00
Small carnivores				
Harbor Blvd	0.16	0.07	0.16	0.04
All other roads	0.05	0.01	0.07	0.01
All species combined				
Harbor Blvd	0.41	0.09	0.33	0.07
All other roads	0.11	0.02	0.12	0.01

Table 6. Mean roadkill indices (roadkills per km per five surveys) for coyotes, small carnivores, and all species combined before (July 2004 – June 2005) and after (July 2006 – June 2007) underpass construction. For both period, n = 9 groups of five surveys. *Significantly difference between before and after periods, P≤0.05.

Species/Location	Before (July 2004-June 2005)		After (July 2006-June 2007)	
	Mean	SE	Mean	SE
Coyotes				
Harbor Blvd	0.10	0.07	0.17	0.08
All other roads	0.01	0.01	0.00	0.00
Small carnivores				
Harbor Blvd	0.10	0.05	0.14	0.08
All other roads	0.07	0.02	0.06	0.02
All species combined				
Harbor Blvd	0.21	0.07	0.31	0.14
All other roads	0.13*	0.02	0.08	0.02

Table 7. Mean number of vehicles per 24-h on Colima Road before, during and after underpass construction, and on Harbor Boulevard before and during construction (data were not available on Harbor Boulevard after construction). On Colima Road, sample size before, during, and after construction was 52, 11 and 4 surveys, respectively. On Harbor Boulevard, sample size before and during construction was 8 and 4 surveys, respectively. Data were obtained from the County of Los Angeles, Department of Public Works (2007).

	Colima Road		Harbor Boulevard	
	Mean	SE	Mean	SE
Before	38,952	386	33,057	667
During	40,629	514	33,698	637
After	40,035	983	-	-

Table 8. Percentages of station-nights with at least one track of each species before, during and after underpass construction. Note that rodent tracks were not identified to species, and 11 tracks were unidentifiable. Numbers in parentheses are the number of station-nights with at least one track of a given species. Data include the additional 5-night sampling session, the track stations along Harbor Boulevard, and track stations in the Harbor Boulevard underpass. There were 405, 435 and 866 station-nights before, during and after construction, respectively.

Species	Before	During	After
Virginia opossum	1 (4)	0 (0)	0 (0)
coyote	62 (252)	70 (303)	68 (589)
gray fox	1 (5)	<1 (2)	1 (6)
northern raccoon	1 (3)	0 (0)	1 (7)
striped skunk	10 (42)	11 (47)	12 (106)
long-tailed weasel	1 (4)	<1 (2)	<1 (2)
American badger	0 (0)	<1 (1)	0 (0)
bobcat	1 (5)	<1 (2)	<1 (4)
mule deer	1 (5)	<1 (1)	3 (27)
desert cottontail	7 (28)	5 (20)	6 (54)
rodents	8 (31)	3 (13)	5 (46)
domestic dog	4 (15)	1 (6)	4 (31)
unknown	1 (5)	1 (3)	<1 (3)

Table 9. Results of Tukey multiple-comparisons tests for differences in track indices among areas for coyotes and striped skunks. For each species, means with the same Tukey grouping letter are not significantly different ($P>0.05$). Sample size was 18 surveys except in area A, where there were 12 surveys.

Species	Area	Mean	SE	Tukey grouping
Coyotes	A	0.91	0.03	A
	C	0.80	0.04	AB
	D	0.78	0.05	AB
	B	0.64	0.06	B
Striped skunks	D	0.25	0.04	A
	B	0.17	0.03	AB
	C	0.08	0.02	B
	A	0.06	0.02	B

Table 10. Mean track-station indices of coyotes and striped skunks during wet (November – March) and dry (April – October) seasons, pooling across all years. For wet and dry seasons, n = 33 surveys each.

Species	Wet Season		Dry Season	
	Mean	SE	Mean	SE
Coyotes	0.81	0.03	0.75	0.05
Striped skunks	0.13	0.02	0.16	0.03

Table 11. Track-station indices, I_{jk} calculated from the first three nights and all five nights of the 5-night track-station sampling period (2 April – 18 June 2007). Significant differences between the number of nights sampled were found only for striped skunks ($t = 2.28$, $DF = 15$, $P = 0.0375$). No new species were detected during the last 2 days of sampling.

Species	3 nights	5 nights
coyote	0.60	0.62
gray fox	0.01	0.01
northern raccoon	0.01	0.01
striped skunk	0.15	0.12
long-tailed weasel	0.01	0.01
mule deer	0.04	0.04
desert cottontail	0.08	0.07
rodent sp.	0.07	0.07
domestic dog	0.06	0.05
Number of species detected	9	9

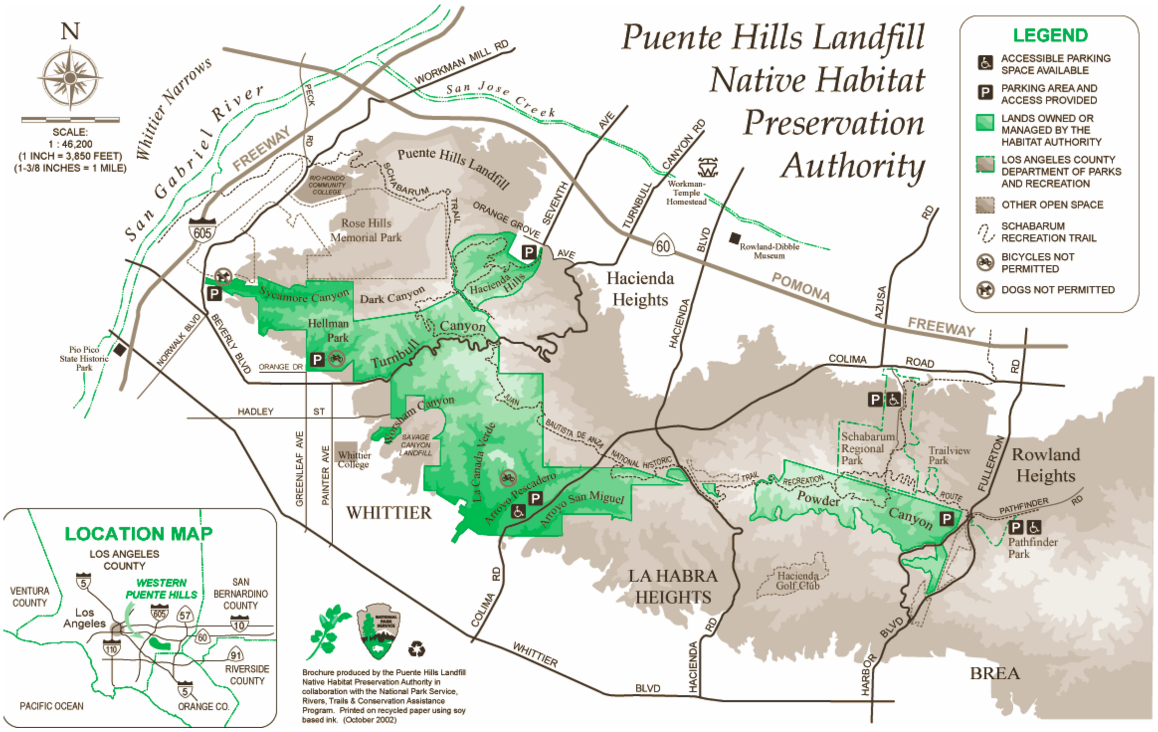

Fig. 1. Map of the western Puente Hills in Los Angeles County, California, showing lands administered by the Habitat Authority. This study was conducted primarily on lands administered by the Habitat Authority and Los Angeles County Public works, as well as on major surface roads in the area. Note Harbor Boulevard on the far east. Map provided by the Habitat Authority.

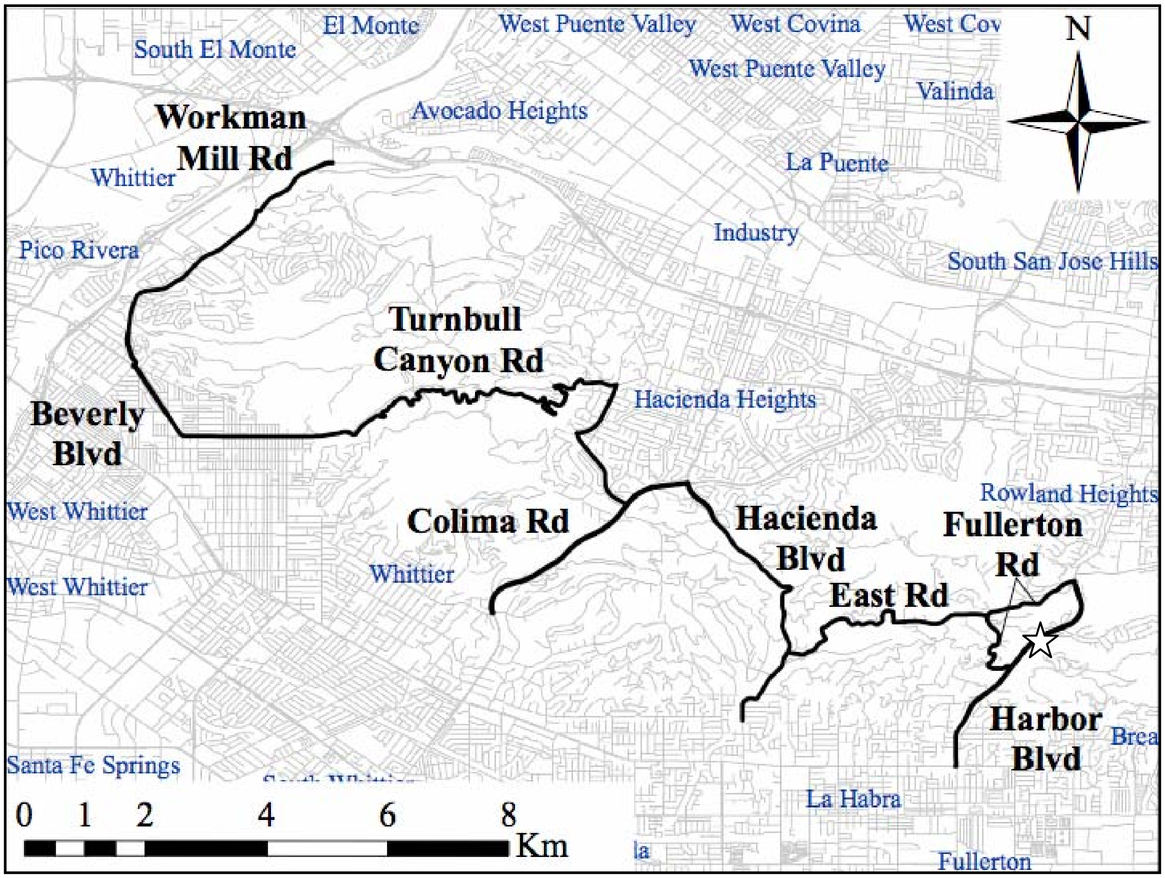

Fig. 2. Roadkill survey route in the Puente Hills, California. The dark highlighted roads were surveyed for roadkills. The white star represents the location of the new wildlife underpass on Harbor Boulevard.

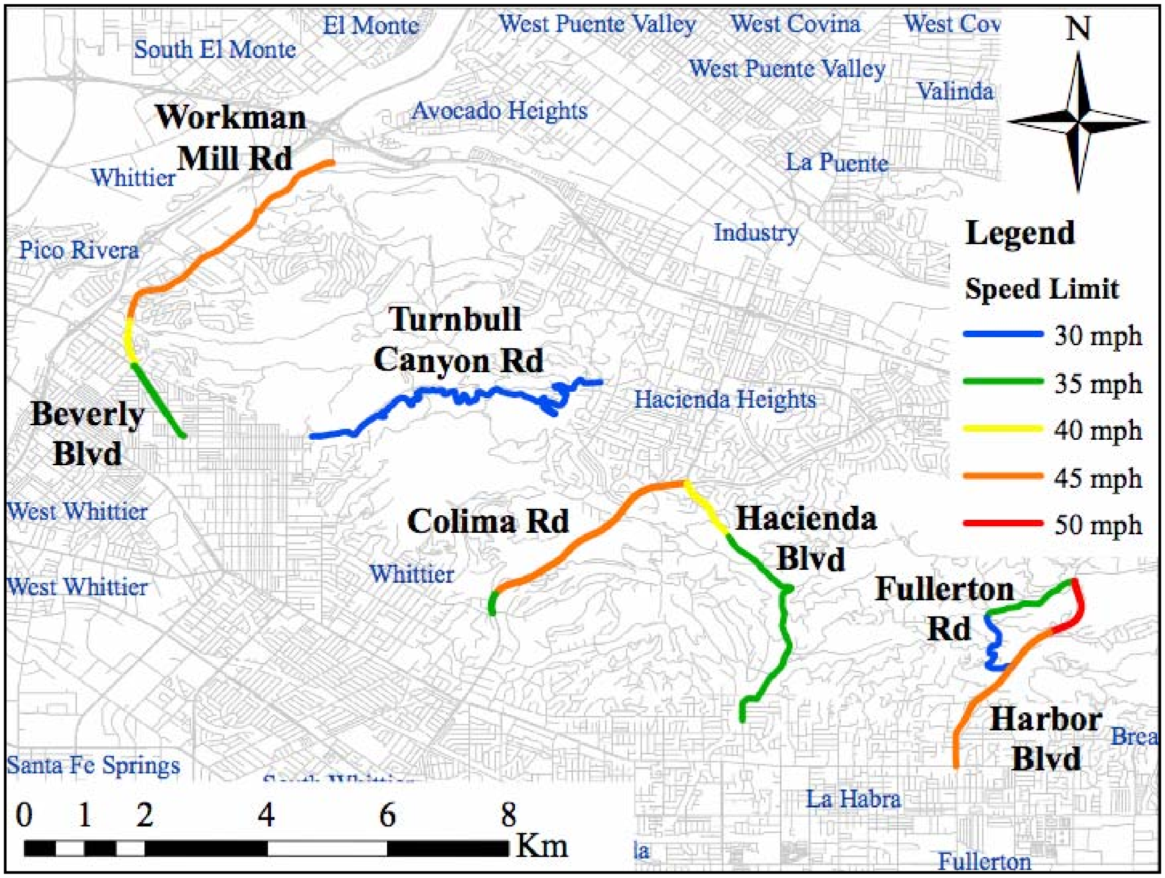

Fig. 3. Posted speed limits on roads in the roadkill survey route. The highlighted roads were those that were used to compare posted speed limit with frequency of roadkills.

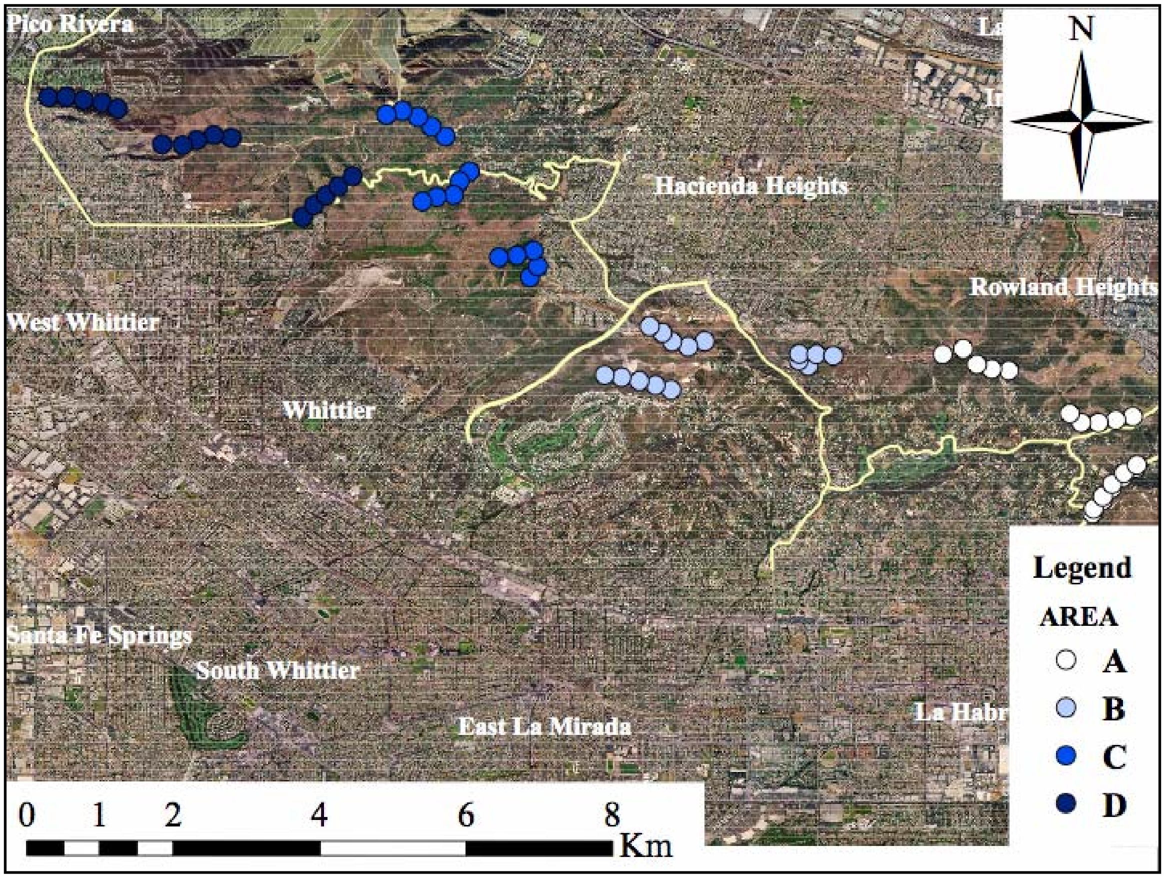

Fig. 4. Locations of track-station transects in the western Puente Hills, Los Angeles County, California. Circles represent individual track-stations, arranged into transects in areas A, B, C, and D. Transects in each area were sampled at the same time. The roadkill survey route is shown in tan for reference.

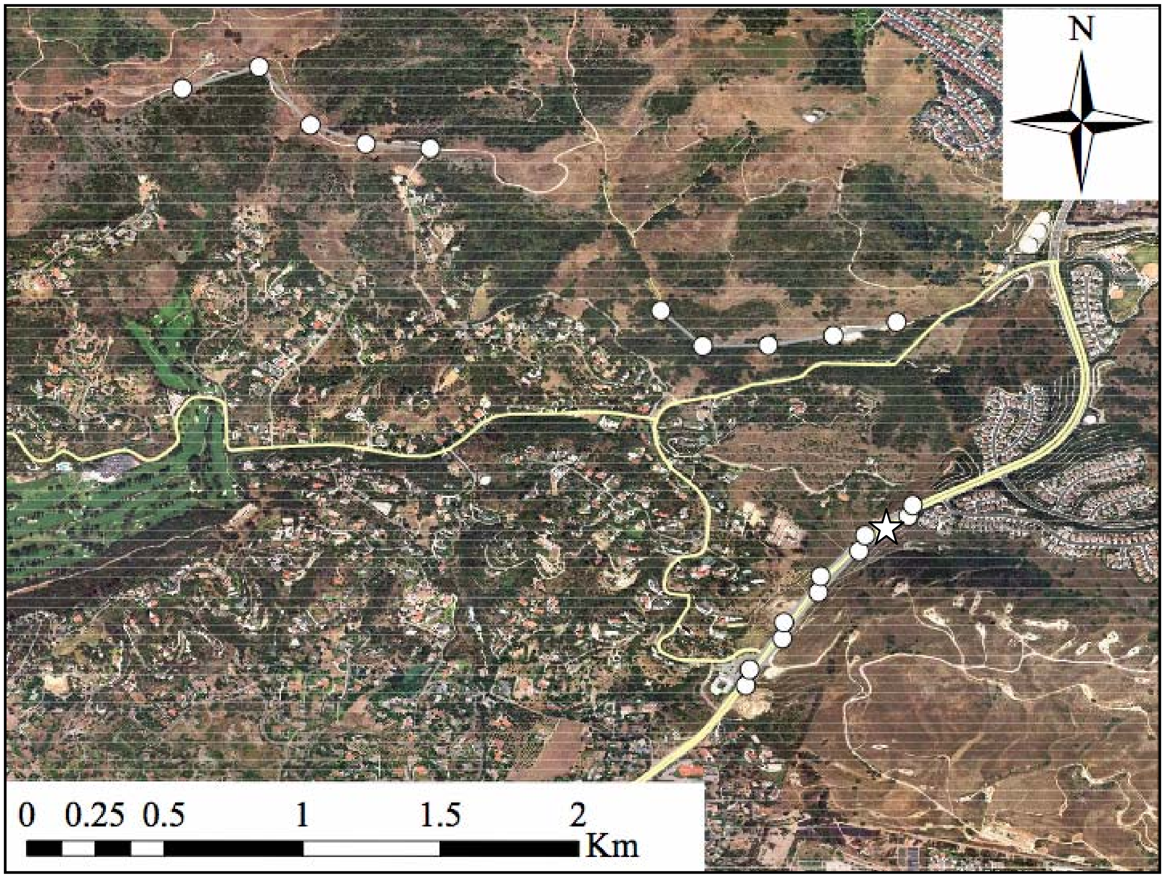

Fig. 5. Detail of locations of track-station transects in area A. Gray lines represent transects; white circles represent individual track-stations. The white star represents the location of the wildlife underpass on Harbor Boulevard. The roadkill survey route is shown in tan for reference.

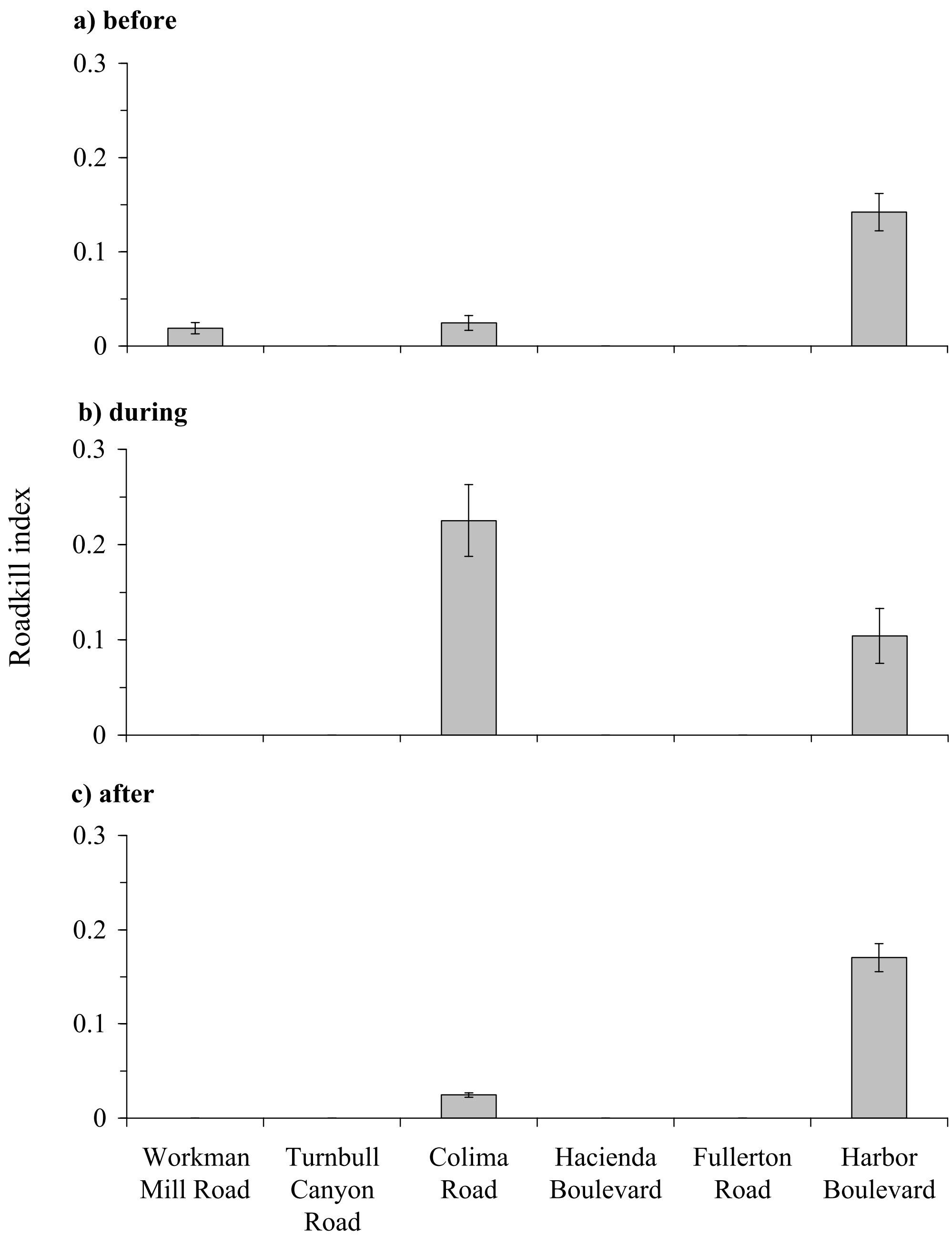

Fig. 6. Mean (± SE) roadkill index for coyotes on each road in the survey route a) before, b) during and c) after underpass construction. Sample size before, during and after construction was 11, 6 and 11 groups of 5 surveys, respectively.

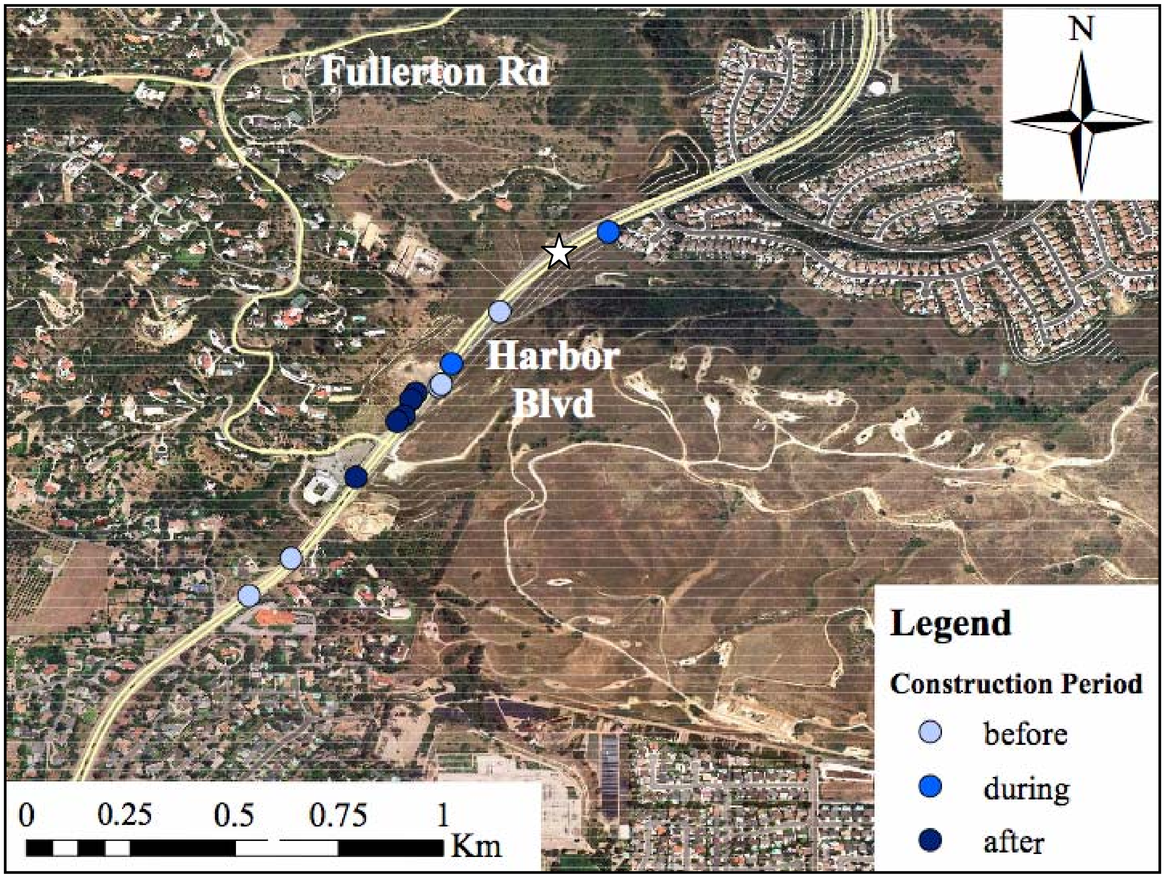

Fig. 7. Locations of coyote roadkills on Harbor Boulevard before, during and after underpass construction. No other location along the roadkill survey route had as many coyote roadkills clustered so close together (12 coyote roadkills in a 1.25 km section). There were 53, 34 and 53 surveys before (Jul 2004 – Sep 2005), during (Oct 2005 – Apr 2006) and after (May 2006 – Jul 2007) underpass construction, respectively. The white star shows the location of the new underpass.

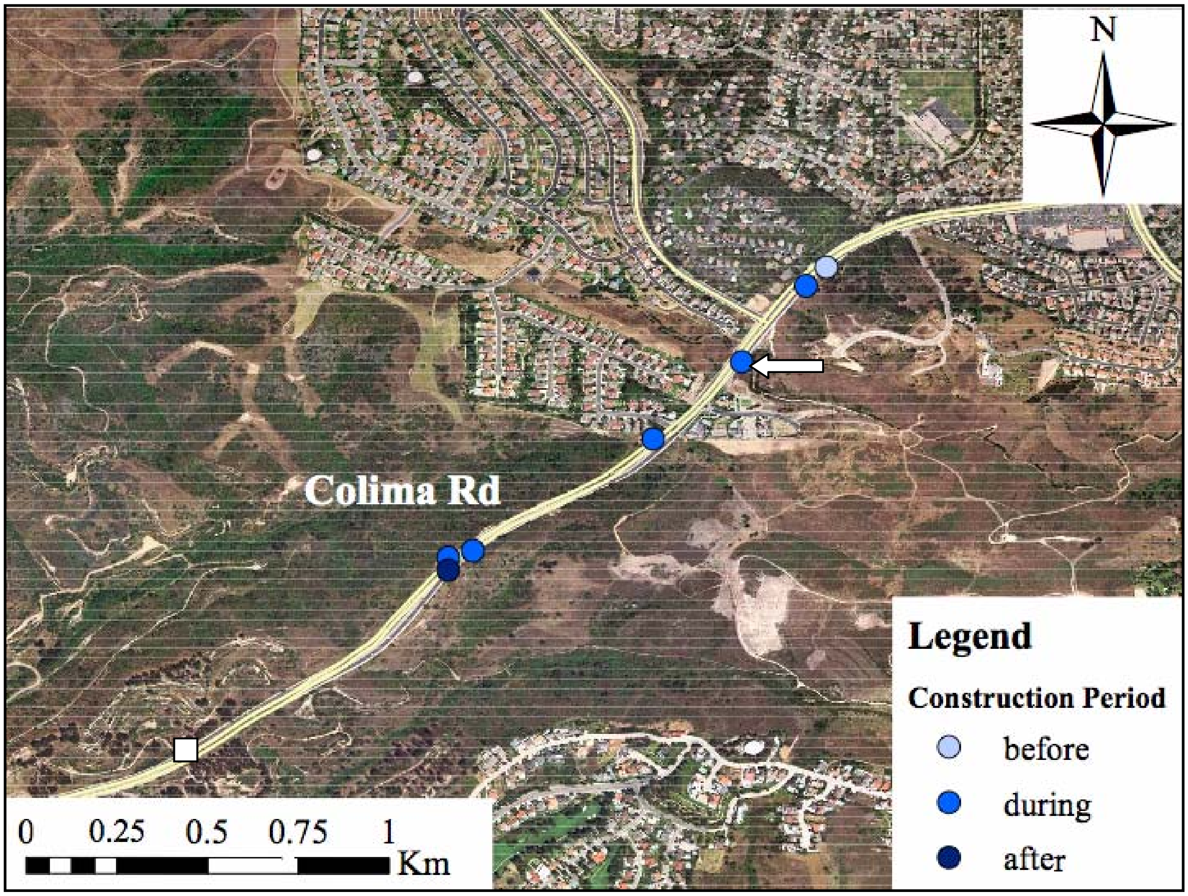

Fig. 8. Locations of coyote roadkills on Colima Road before, during and after underpass construction. There were seven coyote roadkills in a 1.5 km section. There were 53, 34 and 53 surveys before (Jul 2004 – Sep 2005), during (Oct 2005 – Apr 2006) and after (May 2006 – Jul 2007) underpass construction, respectively. The white square shows the location of the existing service tunnel. The white arrow points to the location of the equestrian tunnel.

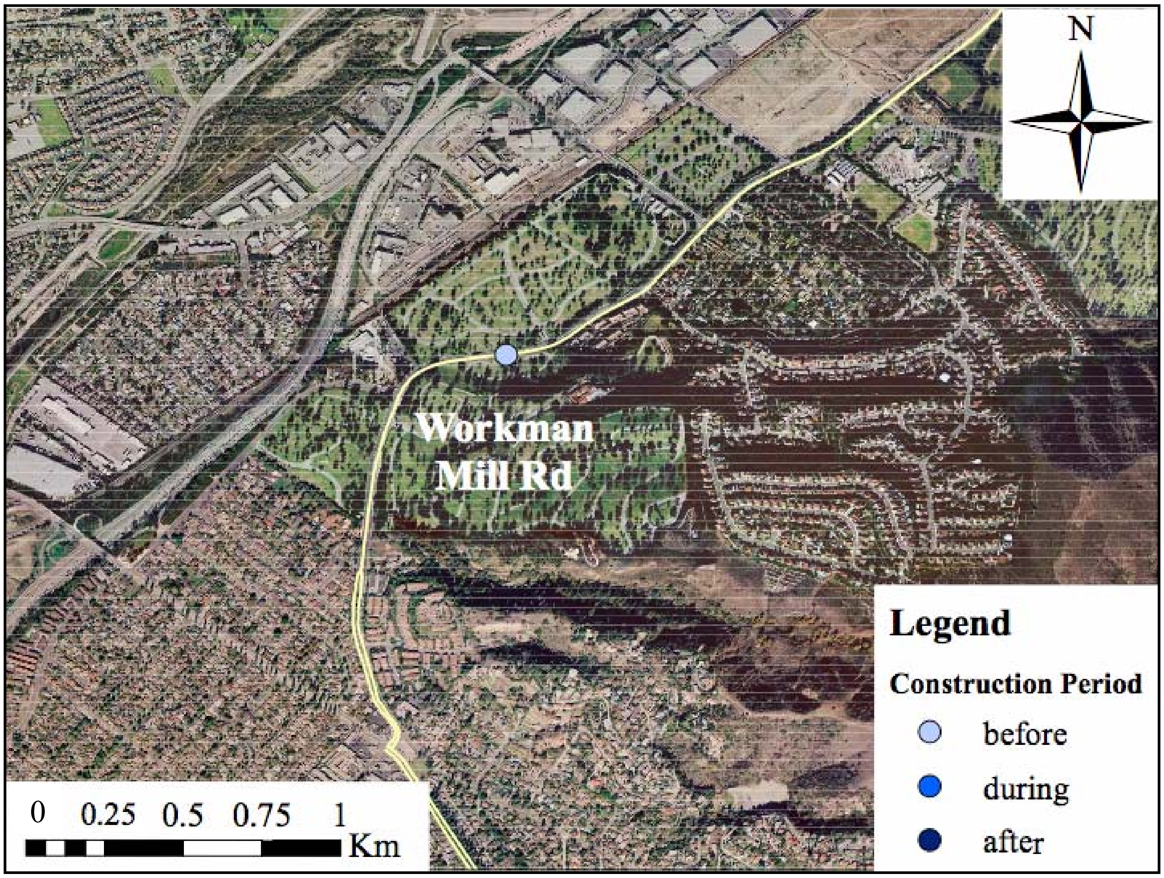

Fig. 9. Location of coyote roadkills on Workman Mill Road. Only one coyote was recorded dead on Workman Mill Road, occurring before underpass construction. There were 53, 34 and 53 surveys before (Jul 2004 – Sep 2005), during (Oct 2005 – Apr 2006) and after (May 2006 – Jul 2007) underpass construction, respectively.

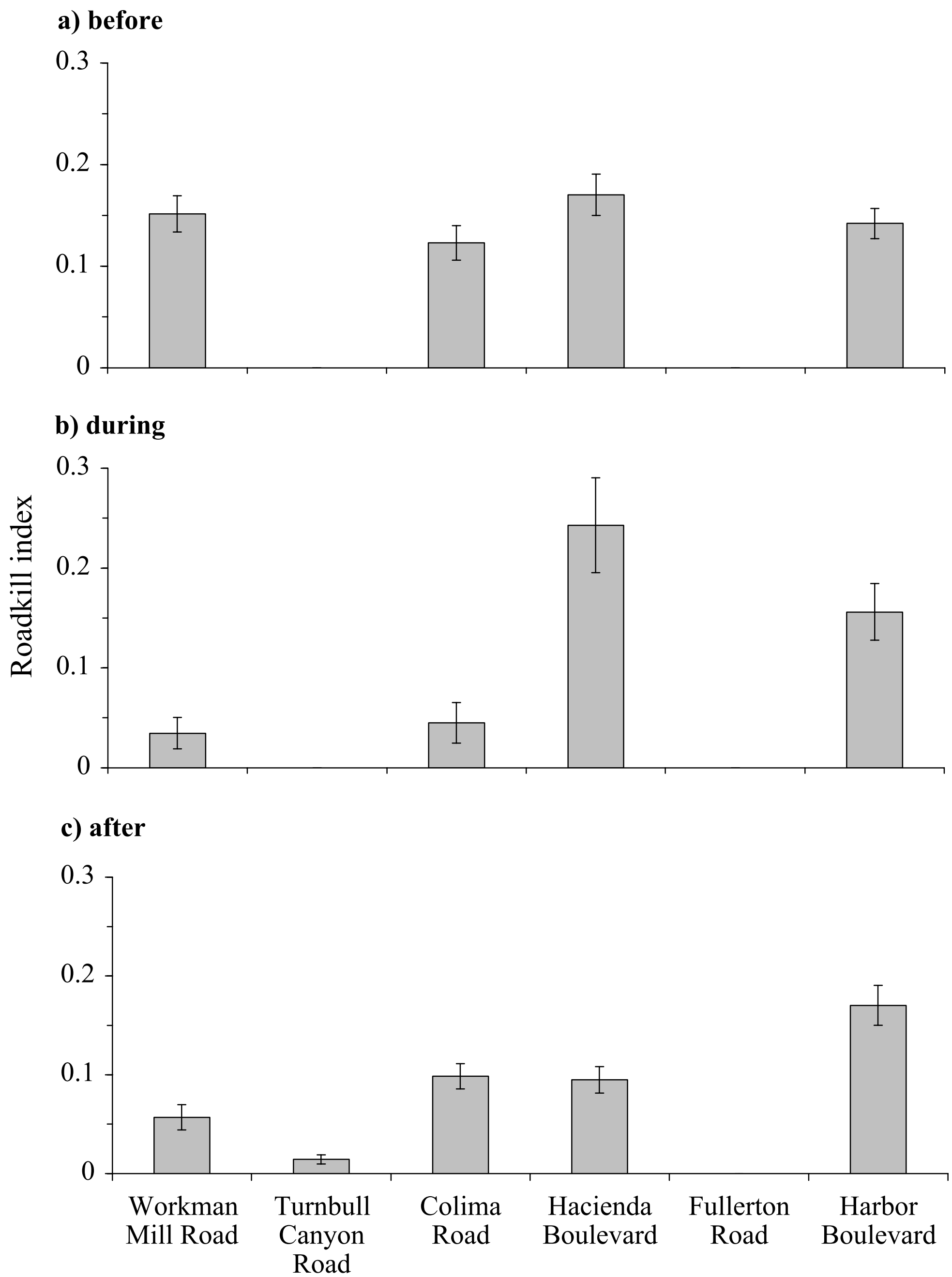

Fig. 10. Mean (± SE) roadkill index for small carnivores on each road in the survey route a) before, b) during and c) after underpass construction. Sample size before, during and after construction was 11, 6 and 11 groups of five surveys, respectively.

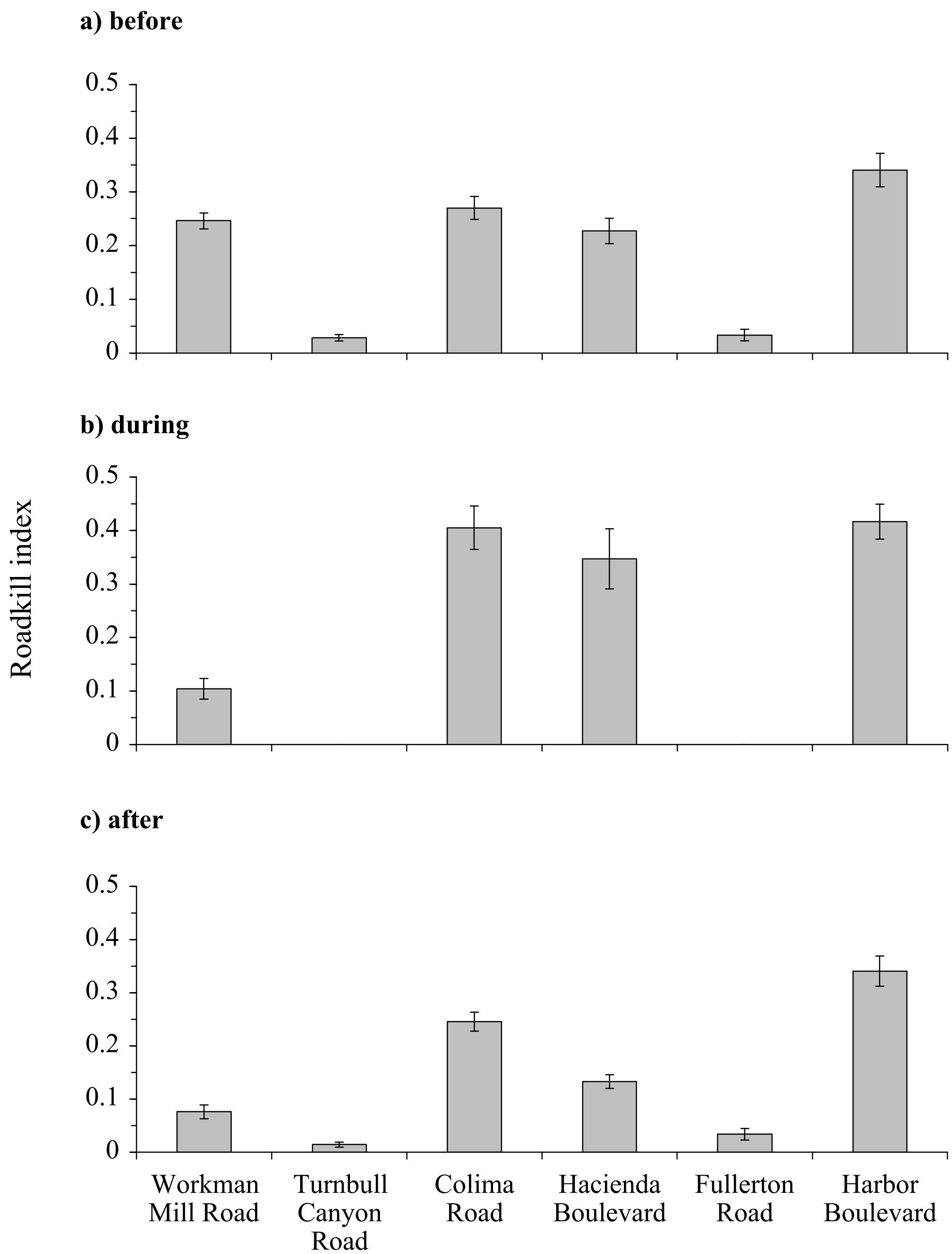

Fig. 11. Mean (± SE) roadkill index for all species combined on each road in the survey route a) before, b) during and c) after underpass construction. Sample size before, during and after construction was 11, 6 and 11 groups of five surveys, respectively.

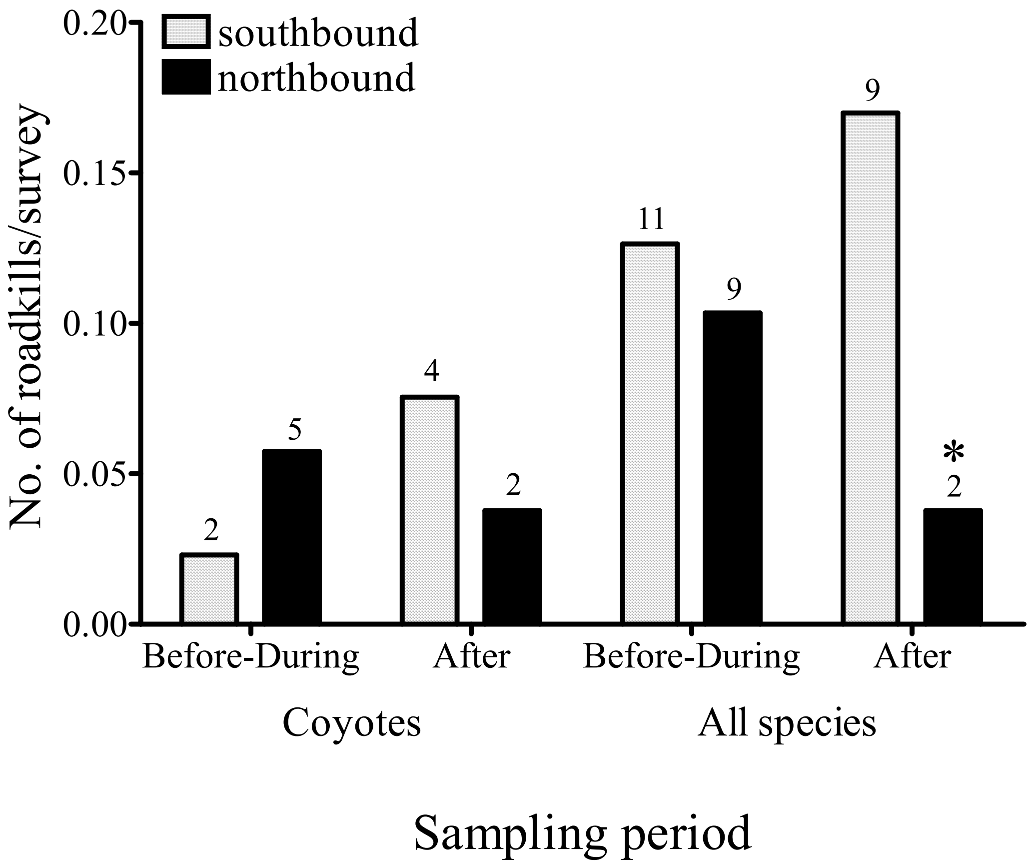

Fig. 12. Frequency of roadkills of coyotes and of all species combined on the southbound (downhill) and northbound (uphill) lanes of Harbor Boulevard. Data are the numbers of roadkills per survey, before and during underpass construction combined, and after the underpass was completed. Numbers over bars are the actual number of roadkills in each lane in each period. Asterisk denotes a significant difference in number of roadkills between lanes for all species combined after construction ($X^2 = 4.45$, d.f. = 1, $P = 0.035$).

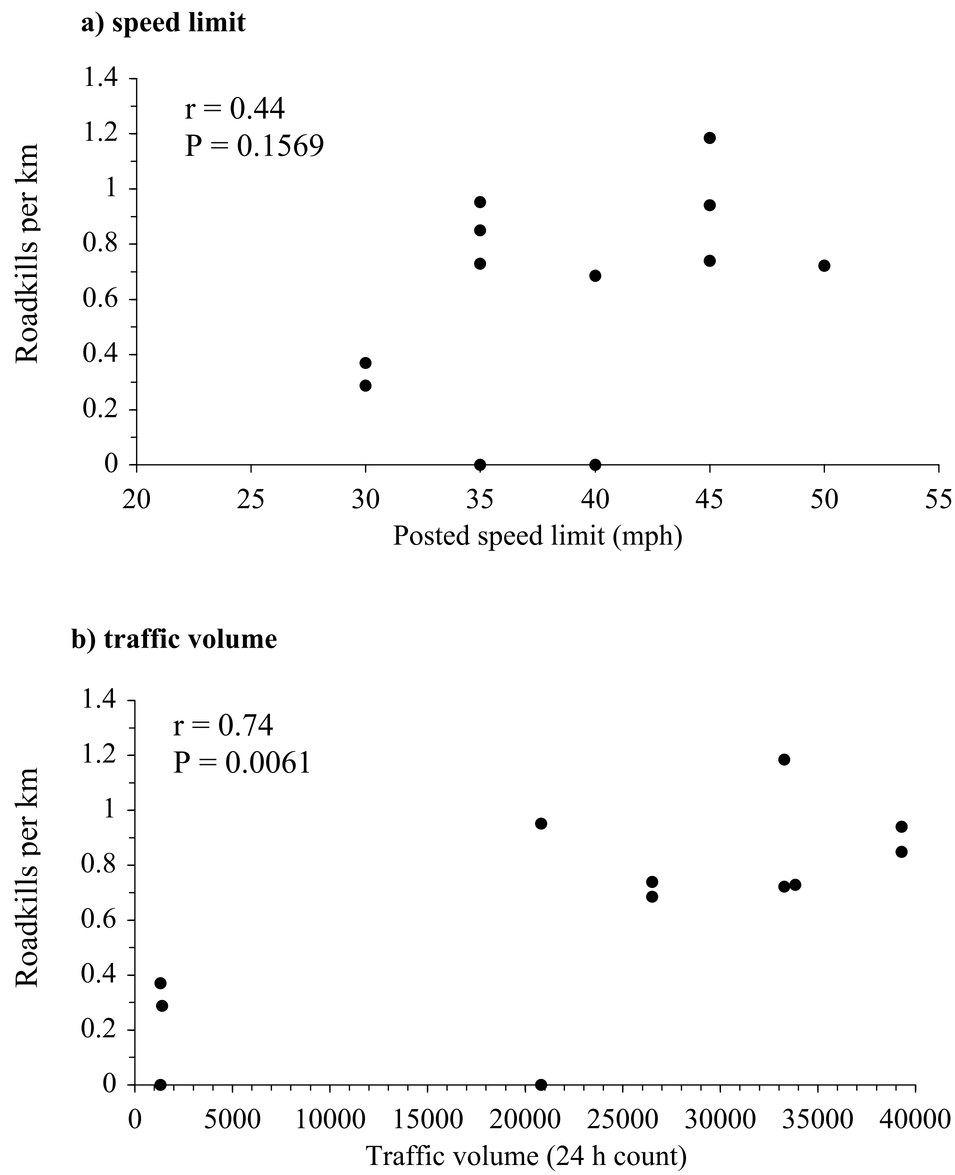

Fig. 13. Number of roadkills per km as a function of a) posted speed limit and b) traffic volume. Sample size was 12 road segments.

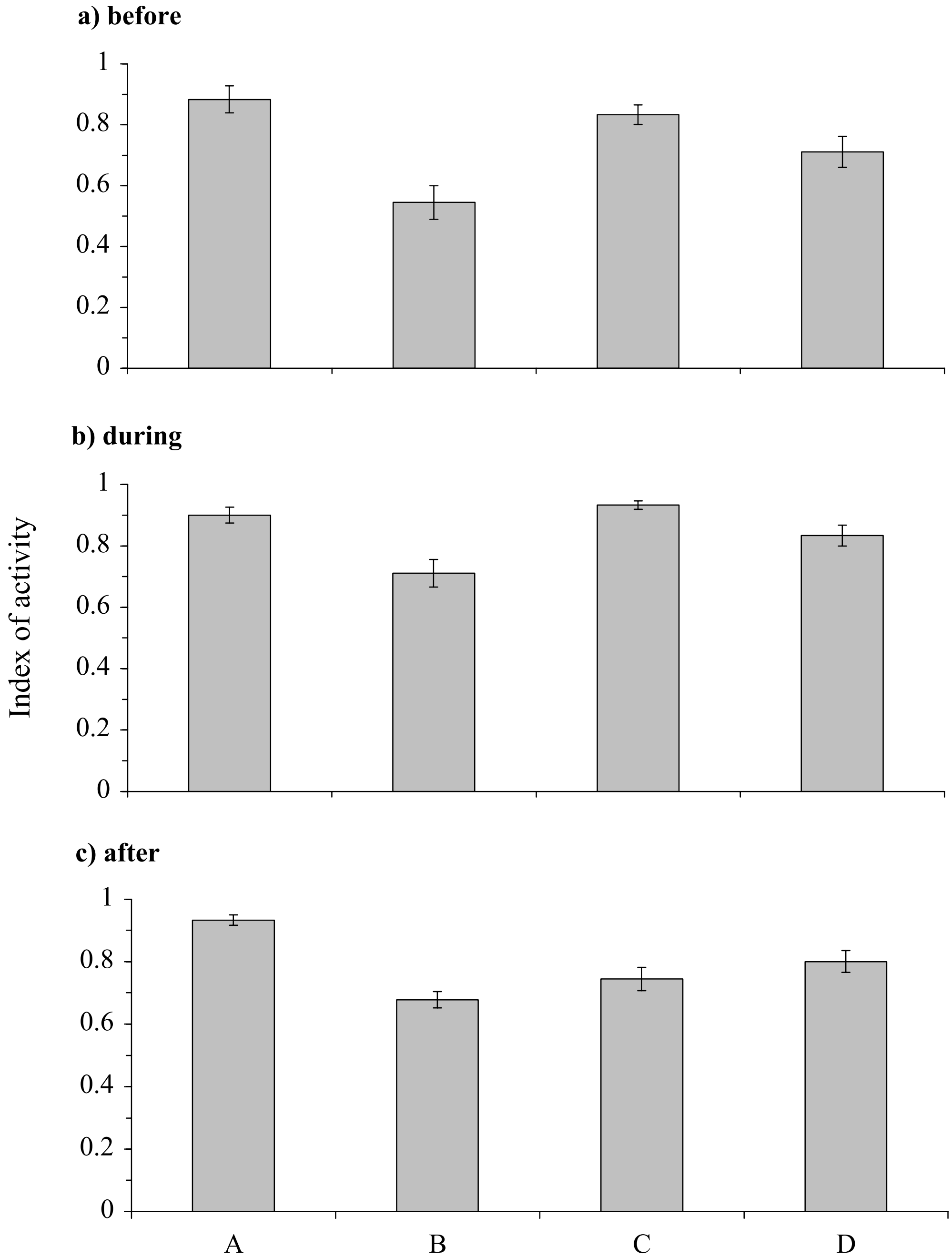

Fig. 14. Mean (± SE) coyote index of activity at track-station transects a) before, b) during and c) after underpass construction in areas from east to west, A, B, C, and D. Track stations on Harbor Boulevard were excluded. Sample size in area A, during each sampling period was 4 surveys. Sample size in areas B, C and D during each sampling period was 6 surveys.

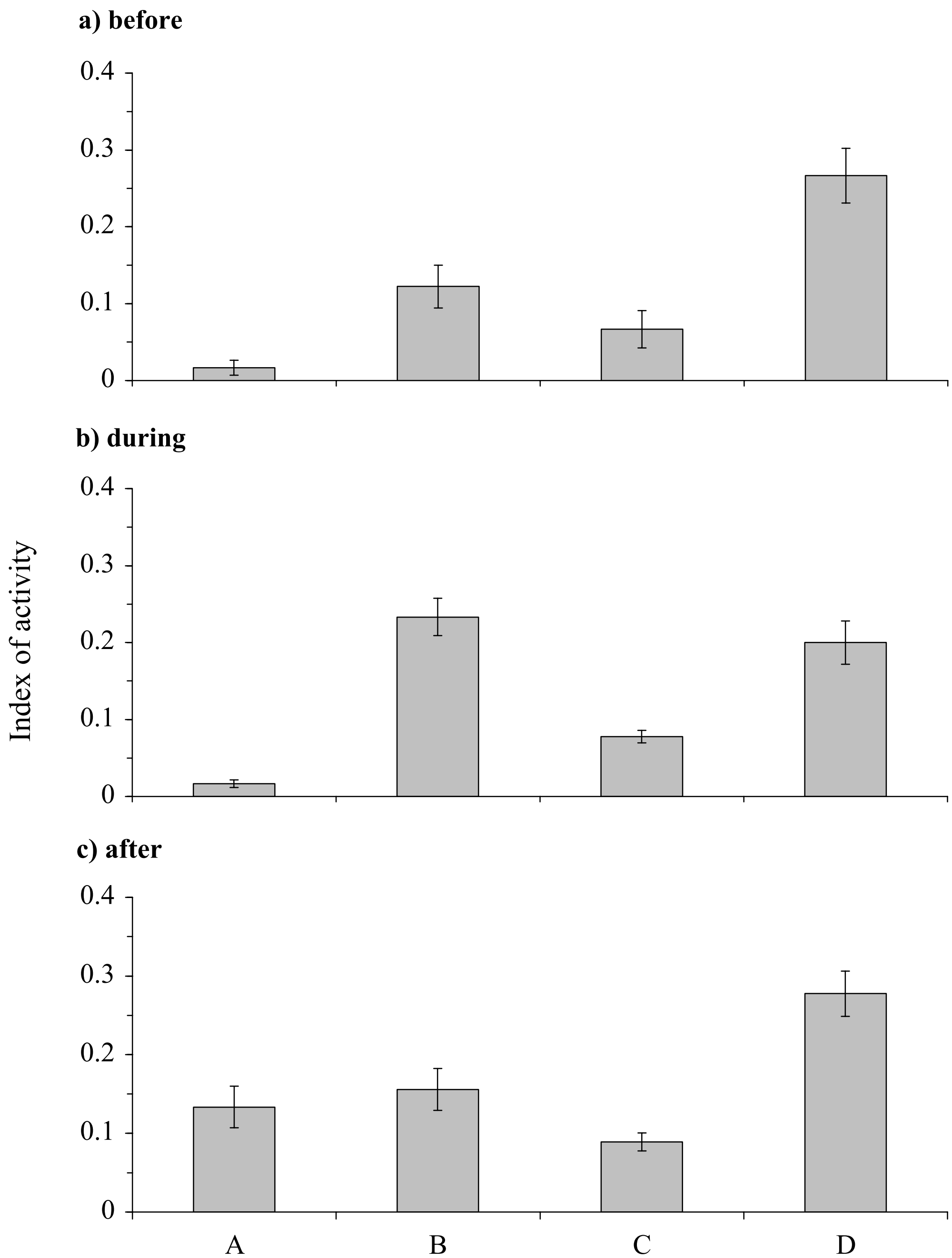

Fig. 15. Mean (± SE) striped skunk index of activity at track station transects a) before, b) during and c) after underpass construction in areas from east to west, A, B, C, and D. Track stations on Harbor Boulevard were excluded. Sample size in area A, during each sampling period was 4 surveys. Sample size in areas B, C and D during each sampling period was 6 surveys.

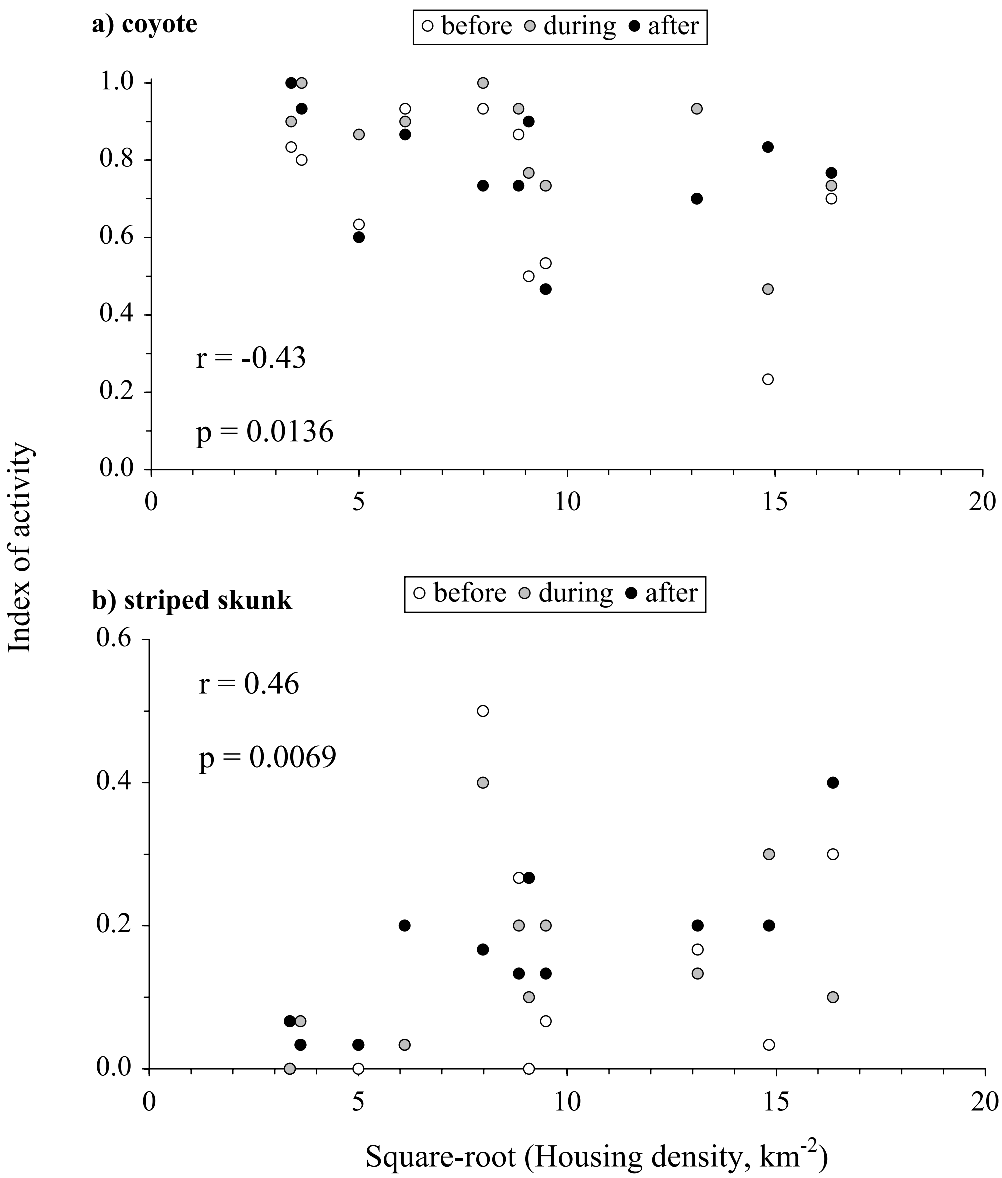

Fig. 16. Index of activity as a function of housing density (km^{-2}) for a) coyotes and b) striped skunks before, during and after underpass construction. Note difference in scale of the y-axes between the two panels. For both coyote and striped skunk, sample size was 11 transects during each sampling period.

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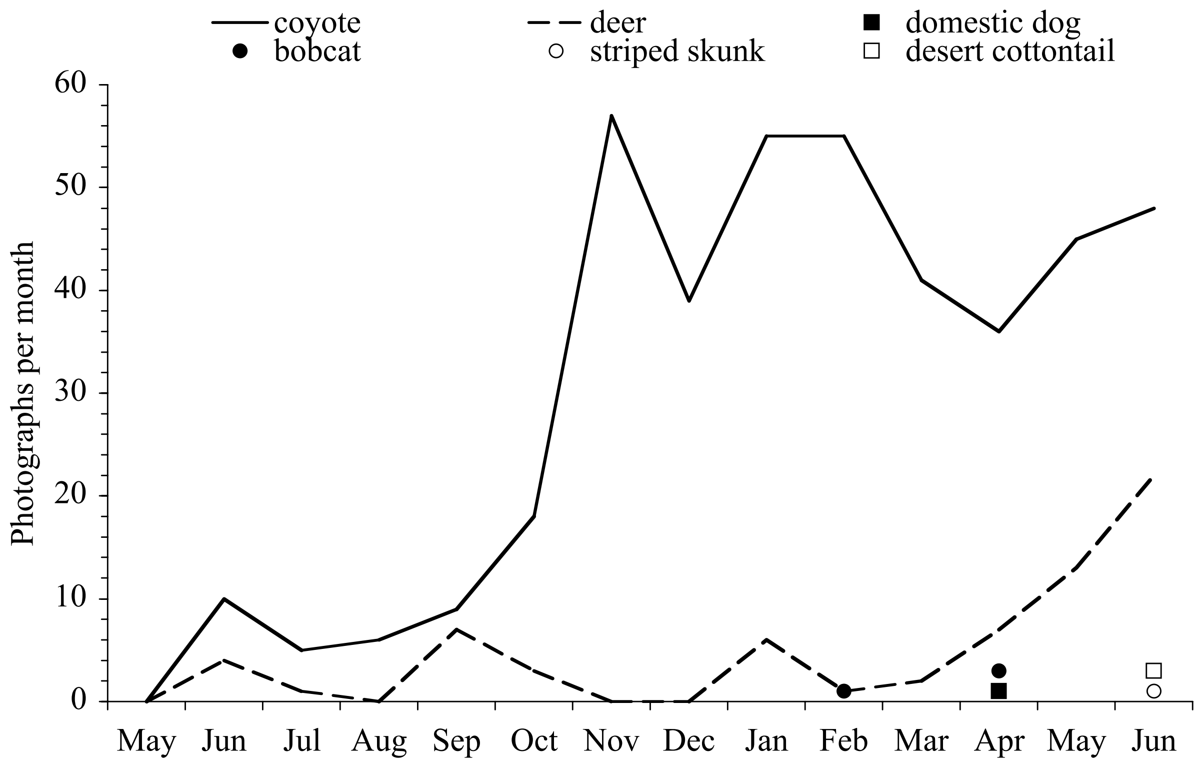

Fig. 17. Number of digital images per month of animals from remote cameras in the Harbor Boulevard wildlife underpass from May 2006 through June 2007.

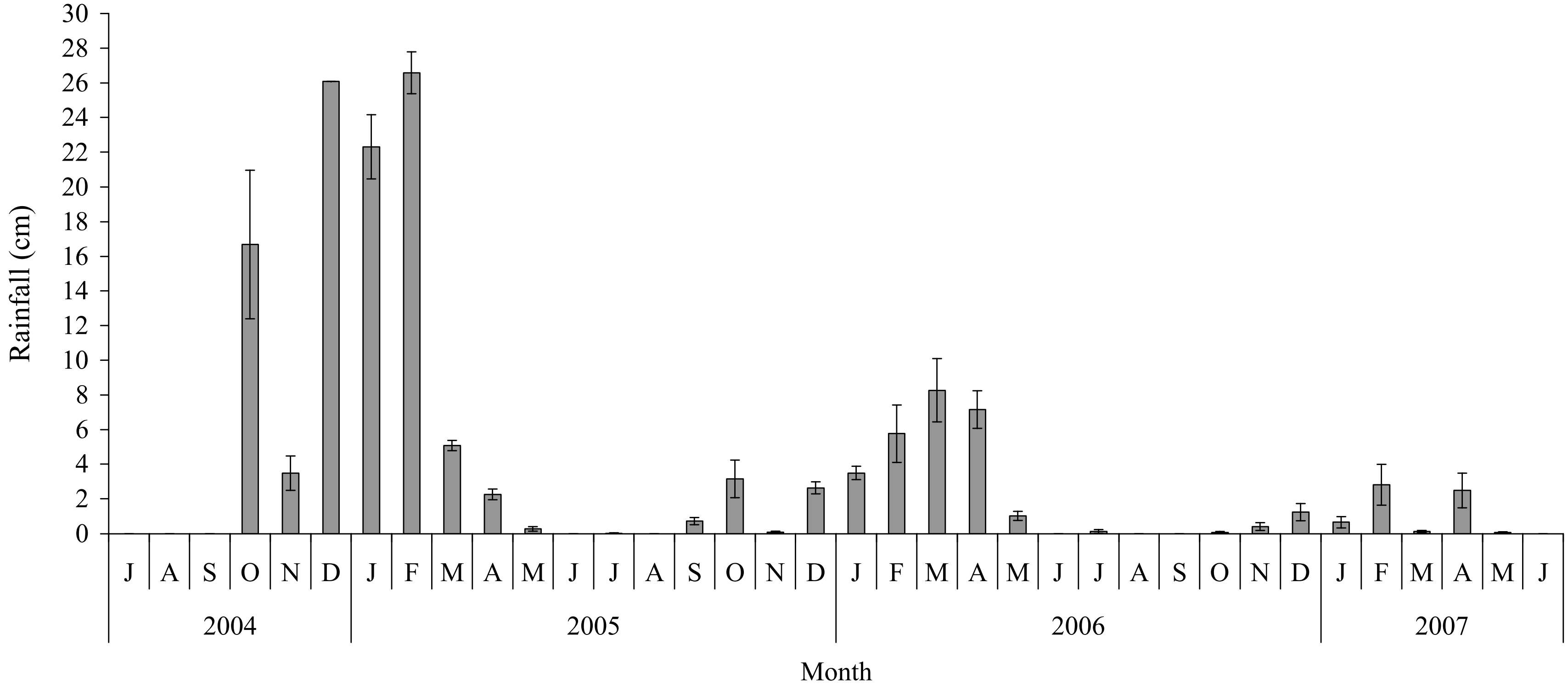

Fig. 18. Mean (± 1 SE) monthly rainfall in the vicinity of the Puente Hills from July 2004 to June 2007. Data were obtained from the Western Regional Climate Center (2008) for five weather stations in the area; however, because data were not available from every station in every month, sample size varied from 1 to 5 stations.