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Characteristics of Elk-Vehicle Collisions and Comparison to GPS-Determined Highway Crossing Patterns

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Abstract: We assessed spatial and temporal patterns of elk (*Cervus elaphus nelsoni*) collisions with vehicles from 1994-2004 (n = 456) along a 30-km stretch of highway in central Arizona, currently being reconstructed in five sections with 11 wildlife underpasses, 6 bridges, and associated ungulate-proof fencing. We used Global Positioning System (GPS) telemetry to assess spatial and temporal patterns of elk highway crossings and compare to elk-vehicle collision (EVC) patterns. Annual EVC were related to traffic volume and elk population levels (r^2 = 0.750). EVC occurred in a non-random pattern. Mean before-construction EVC (4.5/year) were lower than EVC on sections under construction (12.4 EVC/year). On the only completed section, EVC did not differ among before-, during-, and after-construction classes, even though mean traffic volume increased 67 percent from before- to after-construction levels, pointing to the benefit of three passage structures and fencing. On one section under construction, EVC increased 2.5x when fencing associated with seven passage structures was incomplete; EVC dropped dramatically once fencing was completed. We accrued 101,506 fixes from 33 elk (25 females, 8 males) fitted with GPS collars May 2002-April 2004. Elk crossed the highway 3,057 times (mean = 92.6/elk) in a non-random pattern. We compared EVC and crossings at five scales; the strongest relationship was at the highway section scale (r^2 = 0.942). Strength of the relationship and management utility were optimized at the 1.0-km scale (r^2 = 0.701). EVC frequency was associated with proximity to riparian-meadow habitats adjacent to the highway at the section (r^2 = 0.962) and 1.0 km (r^2 = 0.596) scales. Though both fall EVC and crossings exceeded expected levels, the proportion of EVC in September-November (49%) exceeded the proportion of crossings and coincided with the breeding season, migration of elk from summer, and high use of riparian-meadow habitats adjacent to the highway. The proportion of EVC and crossings by day did not differ; both reflected avoidance of crossing the highway during periods of highest traffic volume. Though traffic volume was highest from Thursday-Saturday, the proportion of EVC was below expected. A higher proportion of EVC (59%) occurred relative to crossings (33%) in the evening hours (17:00-23:00); 34 percent of EVC occurred within a one-hour departure of sunset, and 55.5 percent within a two-hour departure. EVC data are valuable in developing strategies to maintain permeability and increase highway safety including selecting locations of passage structures.

Introduction

Recognition and understanding of the impact of highways on wildlife populations have increased greatly in the past decade (Forman et al. 2003), to the extent that these impacts have been characterized as some of the most prevalent and widespread forces affecting natural ecosystems in the U.S. (Noss and Cooperrider 1994, Forman and Alexander 1998, Trombulak and Frissell 2000, Farrell et al. 2002). The direct impact of collisions with motor vehicles is a significant source of mortality affecting wildlife populations. An estimated 500,000 (Romin and Bissonette 1996a) to 700,000 (Schwabe and Schuhmann 2002) deer (*Odocoileus* spp.) alone are killed annually on U.S. highways. Wildlife-vehicle collisions (WVC) cause human injuries and deaths, tremendous property damage, and substantial loss of recreational opportunity and revenue associated with sport hunting (Reed et al. 1982, Schwabe and Schuhmann 2002), and disproportionately affect threatened or endangered species (Foster and Humphrey 1996).

Numerous assessments of spatio-temporal patterns of WVC have been conducted, most focusing on deer (Reed and Woodard 1981, Bashore et al. 1985, Romin and Bissonette 1996b, Hubbard 2000). Only recently have WVC assessments specifically addressed elk (*Cervus elaphus*)-vehicle collision (EVC) patterns (Gunson and Clevenger 2003, Biggs et al. 2004). Insights gained from such assessments have been instrumental in developing strategies to reduce WVC (Romin and Bissonette 1996*a*, Farrell et al. 2002), including planning passage structures to reduce at grade crossings and maintain permeability (Clevenger et al. 2002). Consistent tracking of WVC is a valuable tool to assess the impact of highway construction (Romin and Bissonette 1996*b*) and efficacy of passage structures and other measures (e.g., fencing) in reducing WVC (Reed and Woodard 1981, Ward 1982, Clevenger et al. 2001). Though valuable, no study has investigated or validated the relationships between WVC and spatial and temporal crossing patterns exhibited by wildlife involved in WVC. In fact, Barnum (2003) reported that WVC data were not useful in identifying crossing zones, largely due to inaccurate reporting of WVC.

The application of Global Positioning System (GPS) telemetry to wildlife movement studies has become increasingly popular, cost-effective, and reliable (Rodgers et al. 1996). With continuous automated tracking at set time intervals, reduced observer bias (compared to VHF telemetry), and potential to collect large datasets, GPS telemetry has revolutionized wildlife movement assessment. GPS telemetry is increasingly used to address heretofore-difficult questions (e.g., Anderson and Lindzey 2003), and holds tremendous potential to facilitate highway permeability assessment and determine spatial and temporal highway crossing patterns by wildlife (McCoy 2005, Waller and Servheen 2005, Dodd et al. *In review*).

The objective of our study was to investigate spatial and temporal patterns of EVC along a highway currently being reconstructed and incorporating numerous passage structures and associated ungulate-proof fencing to limit crossings at grade and funnel animals toward underpasses. The incidence of EVC here was a key factor used in the planning and prioritization of passage structures along this highway. This highway is being upgraded in phases, allowing us to compare EVC associated with highway under various stages of construction (e.g., before-, during, and after-construction), as well as validate the prioritization of highway sections. We sought to compare spatial and temporal patterns of EVC to elk highway crossings determined by GPS telemetry as a means to validate the management utility of EVC data in developing strategies to reduce collisions and promote permeability. Lastly, we assessed the influence of traffic volume on temporal patterns of EVC and elk highway crossings.

Study Area

We conducted our study along a 30-km stretch of State Route (SR) 260, beginning 15 km east of Payson, and extending to the base of the Mogollon Rim, in central Arizona (fig. 1). The existing two-lane highway is being upgraded to a four-lane divided highway in five phased sections; in places, the footprint width of the reconstructed highway exceeds 0.5 km. When complete, the highway will incorporate 11 wildlife underpasses specifically intended to reduce at-grade elk crossings and EVC, as well as 6 bridges over large canyons and streams (fig. 1).

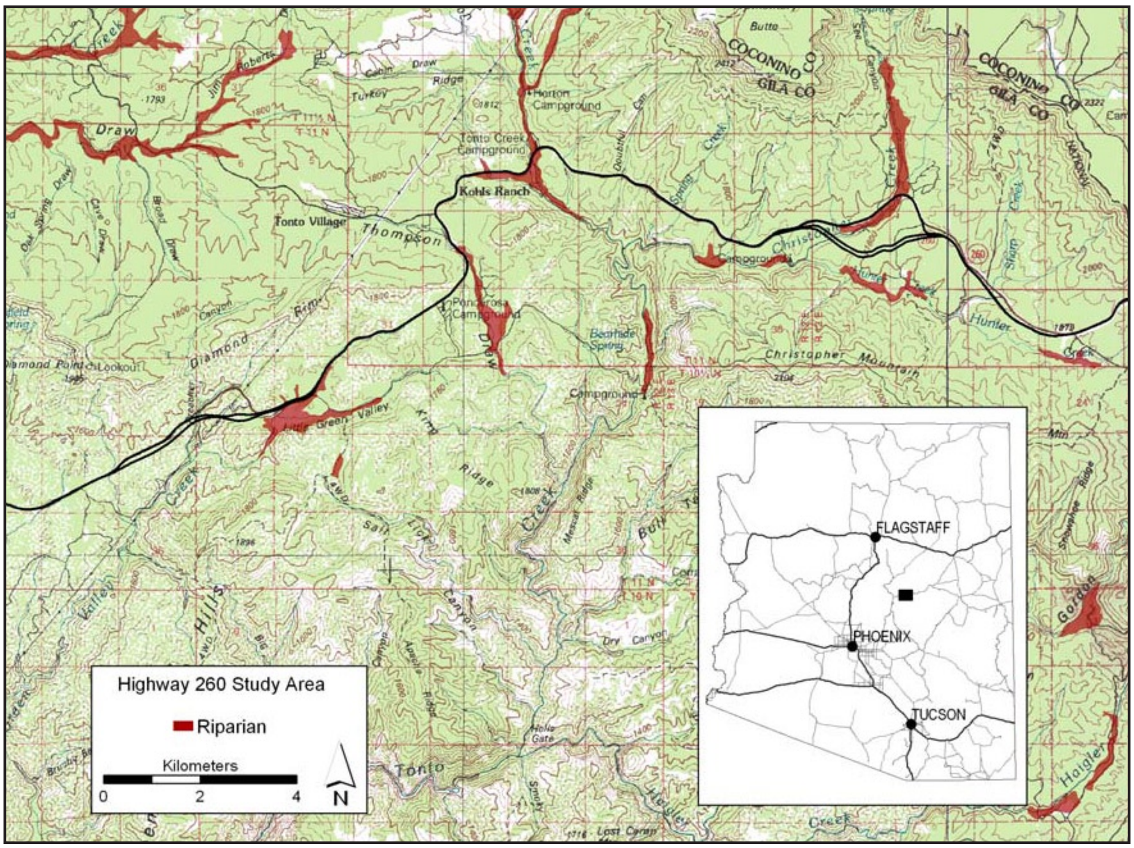

Figure 1. Location of the SR 260 study area, Arizona, USA, including existing and planned wildlife underpasses and bridges on the 5 highway upgrade sections. Riparian/meadow habitats located in proximity to the highway are denoted by shading.

The first section, Preacher Canyon (PC; 4.6 km), was completed and all lanes opened to traffic in November 2001. This section included two-bridged underpasses, in addition to a large bridge; 0.5 km (10%) of the highway was fenced with 2.5-m ungulate-proof fencing associated with the two underpasses. The Christopher Creek Section (CC; 8.2 km) was completed in December 2004, with four wildlife underpasses and three bridges in place since 2003. All lanes were opened to traffic in July 2004 before all fencing associated with underpasses was completed. Here, fencing and alternatives to fencing (e.g., swaths of large rock rip-rap) were implemented along 4.5 km (55%) in association with passage structures. The Kohls Ranch Section (KR; 5.4 km) has been under construction since 2003 and includes one wildlife underpass and two bridges; construction will be completed in late-2005. Construction on the last two sections, Little Green Valley (LGV; 4.0 km) and Doubtful Canyon (DC; 4.5 km), will not be initiated before 2007.

Average annual daily traffic volume (AADT) on this portion of SR 260 doubled in 10 years from 3,124 in 1994 to nearly 6,267 in 2002, and increased to 8,700 (+38%) in 2003 (Source: Arizona Department of Transportation [ADOT] Data Management Section, Phoenix, AZ).

Our study area lies within the ponderosa pine (*Pinus ponderosa*) association of the montane coniferous forest community (Brown 1994*a*). Elevations range from 1,590-2,000 m, and the Mogollon Rim escarpment to the north is the dominant landform, rising precipitously to 2,400 m (fig. 1). Vegetation adjacent to the highway grades from mixed ponderosa, pinyon (*P. edulis*), juniper (*Juniperus* spp.), and live oak (*Quercus* spp.) forest on the lower elevation PC and LGV sections, to forests predominated by ponderosa with interspersed Gambel oak (*Q. gambelii*) at higher elevations to the east. Chaparral (e.g., manzanita; *Arctostaphalus pungens*) with sparse pinyon, live oak, and ponderosa pine is prevalent on the drier south-facing slopes. Numerous riparian and meadow habitats occur at several locations along the highway corridor (fig. 1), with some meadows >150 ha in size. Several perennial streams flow adjacent to portions of the highway, including Little Green Valley (PC), Tonto (KR), Christopher (DC, CC), Hunter (CC), and Sharp (CC) creeks. Climatic conditions for the study area are mild, with a mean maximum monthly temperature (July) for Payson of 32.4oC, and a mean minimum monthly temperature (January) of –6.9oC. Precipitation averages 52.6 cm/year, with a mean of 54.1 cm of snowfall each winter; precipitation has averaged two-thirds of normal since 2002.

Both resident and migratory herds of Rocky Mountain elk (*C. e. nelsoni*) occurred within our study area. Resident elk were common, especially in proximity to meadow and riparian habitats. Elk migrate off the Mogollon Rim with the first snowfall >30 cm, typically in late October (Brown 1990, 1994*b*). Brown (1990) reported that 85 percent of the elk residing within his Mogollon Rim herd unit migrated to an area below but within 10 km of the base of the Mogollon Rim, which encompasses our study area. Elk return to summer range with forage green up at higher elevations (Brown 1990). Whitetail deer (*Odocoileus virginianus cousei*) were frequently seen in our study area, while mule deer (*O. hemionus*) were less common.

Methods

WVC tracking

We used two sources of tracking to assess WVC. Our primary source was a long-term statewide accident database maintained by the ADOT Data Management Section (ADOT database; Phoenix, AZ), including WVC. Most records (86.0%) were logged by the Arizona Department of Public Safety (DPS) Highway Patrol, and reflected dispatcher and accident reports; ADOT maintenance personnel made 11.5 percent of the reports. As such, we considered this database to be a relatively consistent long-term accounting of WVC. Records in this database included the date, time, and location (to the nearest 0.16 km) of the WVC, the wildlife species (genus only in the case of deer) involved, and the reporting agency. Generally, this database did not include sex and age data. For our assessment, we queried the database for WVC that occurred along that portion of SR 260 in our study area (MP 259-280) from 1994-2004. This database was used as our basis to assess long-term trends in WVC and relationships to highway construction.

At the onset of our project in late-2000, we developed and disseminated a WVC tracking form for use by agencies and research project personnel to document all WVC (including roadkills) along SR 260. This database reflected concerted efforts to regularly search for and document WVC along SR 260, especially by project personnel. Of the reports compiled for 2001-2004, 57.6 percent were submitted by DPS, most which were also logged in the ADOT database. Arizona Game and Fish Department (AGFD) personnel accounted for the remainder (42.4%) of the records in our database, of which none were logged into the ADOT database. Our database included the same information as the ADOT database, along with the sex and age of wildlife involved in WVC, species of deer, and road and weather conditions. WVC were recorded to the nearest 0.16 km. We relied on this database to characterize the sex and age of wildlife involved in WVC, as well as to assess the proportion of WVC that were logged in the ADOT database.

From both databases, we calculated the day of week and departure from sunrise or sunset when the WVC occurred where accurate date and times were known. For temporal and spatial analyses involving WVC, we combined all unique records from both databases.

EVC relationships to AADT and elk population estimates

We assessed the relationships of EVC to AADT and elk population estimates for the management units encompassing our study area for 1994-2003. AADT estimates were obtained from the ADOT Data Management Section (Phoenix, AZ), and were calculated based on annual traffic sampling conducted along SR 260 midway though our study area.

Our elk population estimates (pre-hunt) were obtained from the annual elk management summaries (1994-2003) for Game Management Units (GMU) 22 and 23 (AGFD Game Branch, Phoenix, AZ); we combined the estimates as our study area was split equally by the two GMU. Though the entire estimated elk population for the two GMU did not reside in the vicinity of SR 260, we nonetheless used the estimates as an index to relative population levels that fluctuate from year to year based on calf recruitment, hunter success, and drought conditions that affected elk distribution. We also used this population survey data to compare the surveyed bull:cow ratios (expected) for 2001-2004 to the bull:cow ratio of animals involved in EVC (observed) during the same period using X^2 analysis.

We used linear regression (Neter et al. 1996) to assess the association between EVC and AADT and elk population estimates. We assessed the relationship of EVC to AADT and elk population estimates combined by multiple regression, and assessed the relative importance of independent variables by partial regression analysis (Neter et al. 1996).

Comparison of EVC by highway section and construction classes

We tested the hypothesis that our observed SR 260 EVC did not differ from a randomly generated (discrete) distribution using a nonparametric Kolmogorov-Smirnov test, sensitive to both the difference in ranks and shape of the distributions (Statsoft 1994). We compared EVC among highway sections by calculating mean EVC rates (EVC/km/year) that accounted for differential section lengths. We used analysis of variance (ANOVA; Hays 1981) to assess differences in mean EVC rates among sections, with separate analyses for all years and pre-construction years only. For significant ANOVA tests, we assessed pairwise differences in mean EVC rates with Sheffe's post-hoc multiple comparison tests (Hays 1981). We compared mean EVC among highway construction classes (before-, during, and after-construction) using analysis of covariance (ANCOVA; Hays 1981). We controlled for AADT effects (covariate) in our ANCOVA analysis. We used Sheffe's multiple comparison tests to assess pairwise differences in mean EVC among construction classes.

GPS telemetry assessment of elk highway crossings

We captured elk at 10 sites spaced an average of 2.7 km (±0.7 SE) along SR 260. We primarily trapped elk in net-covered Clover traps (Clover 1954) baited with salt and alfalfa hay; all traps were within 300 m of the highway corridor. We also captured elk with a 12.8 x 12.8 m remote-triggered drop net. Animals were physically restrained, blindfolded, ear tagged, and fitted with GPS receiver collars. We timed trapping to target resident elk to maximize year-long acquisition of GPS fixes near the highway.

We used two models of GPS collars (Telonics, Inc., Mesa, Arizona). We used 19 "store-on-board" receiver collars programmed to receive a fix every two hours, and four programmed to acquire fixes every 1.5 hours from 17:00-9:00 hours (12 fixes) and one at 12:00; operational battery life was 22 months. We also deployed five collars with ARGOS satellite uplink capabilities for rapid data return in early adaptive management activities. These collars were programmed to receive fixes every four hours (15-month battery life). All collars had VHF beacons, mortality sensors and programmed release mechanisms to allow recovery.

We employed ArcGIS® Version 8.3 software (ESRI, Redlands, California) to analyze GPS data. We divided the length of SR 260 within our study site into 200 sequentially numbered 0.16-km segments to quantify highway crossings (fig. 2); these segments were referenced to the 0.16-km milepost segments to which WVC were assigned. To infer highway crossings, we drew lines connecting all consecutive GPS fixes (fig. 2). Crossings were identified where lines between fixes crossed the highway (or either set of divided lanes) through a 0.16-km segment (fig. 2). Animal Movement ArcView Extension Version 1.1 software (Hooge and Eichenlaub 1997) was used to assist in elk crossing determination by individual animal and segment, date and time.

To account for the number of individual elk that crossed at each highway segment, as well as evenness in crossing frequency among animals, we calculated Shannon diversity indices (SDI; Shannon and Weaver 1949) for each segment. We used SDI to calculate weighted crossing frequency estimates for each highway segment, multiplying uncorrected crossing frequency x SDI. Weighted crossings thus reflected the crossing frequency, number of crossing elk, and equity in distribution among crossing elk. We assessed the similarity in our observed elk crossing distributions along SR 260 to a randomly generated (discrete) distribution using a Kolmogorov-Smirnov test. We also used this test to compare the elk crossing frequency distributions for uncorrected versus weighted crossing distributions for all highway segments and sections.

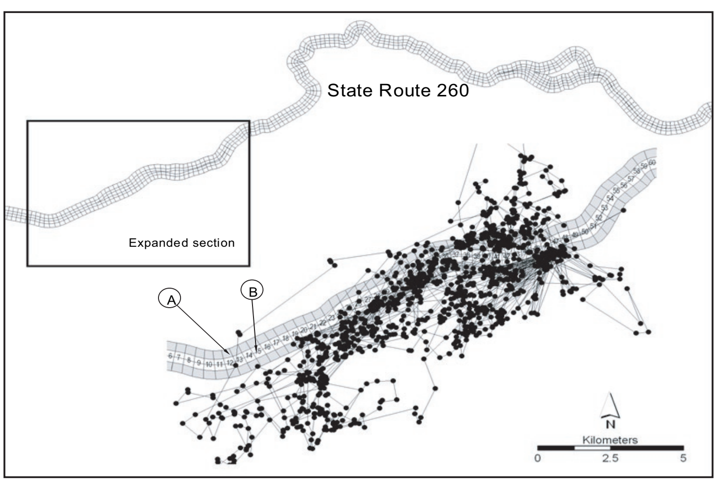

Figure 2. Highway segments (0.16 km) delineated for the SR 260, Arizona, USA, study area, used to compile EVC and highway crossings by elk. The expanded section shows GPS locations and lines between successive fixes to determine approaches within 0.25 km of the highway (shaded band) and crossings. Example A denotes an approach and subsequent highway crossing while B depicts an approach without a crossing.

Comparison of EVC and elk highway crossings
Spatially, we used linear regression to assess the association between the frequency of EVC and elk highway crossings along SR 260, using both uncorrected and weighted elk crossings. To assess the strength of associations at various scales, we compared EVC to crossings at the 0.16-km segment scale, and aggregated the data to 0.5 km, 1.0 km, 1.6 km, and highway section scales for regression analyses. Among scales, we compared correlation coefficients (r) and coefficients of determination (r^2) derived from each regression comparison of EVC to crossings.

Due to the important role that riparian-meadow habitats played in influencing elk highway crossings along SR 260 (Dodd et al. *In review*), we assessed the association between proximity to riparian-meadow habitats and EVC and highway crossings. We used linear regression to measure the association between EVC at the highway section and 1.0-km scales with the number of 0.16-km segments in which riparian/meadow habitat was located within 0.25 km.

We conducted comparisons of EVC and elk crossings by month, day, and time (2-hour intervals), and used X^2 testing to compare observed versus expected temporal values for EVC to those for elk crossings. Also, assuming that the proportion of elk crossings by month, day, and time reflected the expected proportion in which EVC would occur, we compared the proportion of elk crossings (expected) to the actual proportion of collisions that occurred (observed) using X^2 testing. Comparisons by time used only crossings determined from GPS fixes acquired 1.5 or 2 hours apart; we used the interval midpoint as the time for comparisons with WVC. We compared deer-vehicle collisions to EVC relative to month, day, and time, as well as absolute departure from sunrise or sunset. We used mean daily AADT factors for SR 260, obtained from the ADOT Data Management Section to adjust for differential daily AADT (e.g., 7,770 on Sunday versus 10,235 on Friday using the 2003 AADT) when assessing elk and deer collisions with vehicles by day; the product of WVC frequency x daily AADT factors was used to account for the influence of traffic volume.

We defined high EVC and elk crossing (weighted) sections along SR 260 at the 1.0-km scale (total n = 28), using a procedure similar to that described by Malo et al. (2004), predicated on the Poisson distribution. With this procedure, high ECV or crossing thresholds were determined to occur where P = 0.05, using the formula from Agresti (1996:4), where y is the threshold value and u is the mean EVC or crossing level:

$$P_{(y)} = (e^{-u}u^{y})/y!$$

We compared high EVC and crossing sections at or above threshold levels to the location of completed and planned wildlife passage structures along SR 260.

All statistical tests were performed using the program Statistica® (Statsoft, Inc. 1994). Results were considered significant at $P < 0.05$. Mean values were reported with ± SE.

Results

From 1994 to 2004, 395 WVC were recorded in the ADOT database (table 1), for an average of 35.9 WVC/year (±2.5). Of these WVC, 81.5 percent involved elk, and 16.4 percent involved deer species (table 1). Also, three black bears (*Ursus americanus*), one mountain lion (*Puma concolor*), and one javelina (*Tayassu tajacu*) were killed in WVC (table 1).

Between 2001 and 2004, we documented 222 WVC (table 2) compared to 161 in the ADOT database for the same period; elk accounted for 87.4 percent of our WVC (table 3), and deer, 11.6 percent. Of the classified elk, cows were involved in EVC >4x as frequently as bulls, and adult elk accounted for 74.2 percent of the EVC (table 2). Of the classified deer, 70 percent were whitetail versus 30 percent mule deer. In comparing the two WVC databases, 72.5 percent of all WVC were recorded in both databases. A mean of 72.7 percent of our EVC were recorded in the ADOT database (table 3), and ranged from 51.8 percent (2004) to 96.7 percent (2001).

EVC relationships to AADT and elk population estimates
From 1994-2004, WVC increased at a mean rate of 4.7 percent/year, while AADT increased 11.2 percent/year up to 2002, with a 38.8-percent increase in AADT between 2002 and 2003 alone, and 17.8-percent overall (table 1). The elk population estimate for the management units encompassing our study area ranged from 1,488 to 1,716 elk (table 1).

Table 1. Frequency of wildlife-vehicle collisions by species and average annual daily traffic (AADT) volume for SR 260, Arizona, USA, and elk population estimates for management units adjacent to SR 260, for the period 1994-2004

	No. wildlife-vehicle collisions [a]					Elk
Year	Total	Elk	Deer	Other [b]	AADT [c]	Population [d]
1994	29	20	9	0	3,124	1,683
1995	32	25	5	2	3,123	1,678
1996	29	23	6	0	3,652	1,665
1997	31	27	4	0	3,750	1,672
1998	45	33	10	2	3,950	1,660
1999	47	39	7	1	4,930	1,710
2000	21	14	7	0	5,112	1,542
2001	33	29	3	1	4,500	1,716
2002	44	36	8	0	6,267	1,587
2003	40	34	4	2	8,700	1,488
2004	44	42	2	1	N/A	N/A

[a]Source: ADOT Data Management Section, Phoenix, AZ
[b]Black bear, mountain lion, javelina
[c]Source: ADOT Data Management Section, Phoenix, AZ
[d]Source: GMU 22 and 23 annual elk summaries; AGFD Game Branch, Phoenix, AZ

Table 2. Number of total animals killed in wildlife-vehicle collisions along SR 260, Arizona, USA, between 2001-2004, with age and sex of classified animals and proportion of classified animals

	No. of animals killed in w ildlife-vehicle collisions										
		Sex (% of total classified) [a]				Age (% of total classified) [a]					
Species	Total	Female		Male		Adult		Yearling		Young	
Elk	194	106	(80.9)	25	(19.1)	98	(74.2)	15	(11.4)	19	(14.4)
Whitetail deer	12	4	(36.3)	7	(63.6)	9	(81.8)	1	(9.1)	1	(9.1)
Mule deer	5	5	(100.0)	-	-	4	(80.0)	-	-	-	-
Deer	8	5	(83.3)	1	(16.7)	5	(100.0)	-	-	-	-
Black bear	1	-	-	1	(100.0)	1	(100.0)	-	-	-	-
Mountain lion	1	-		1	(100.0)	-	-	1	(100.0)	-	-

[a]Unclassified records account for differences between totals and number by sex and age

The association between EVC and AADT accounted for only 20 percent of the variation in EVC (r = 0.449, r^2 = 0.202, P = 0.192, n = 10), while the association between EVC and elk population estimates explained <1% of the variation (r = 0.088, r^2 = 0.007, P = 0.807, n = 10). However, when we incorporated both AADT and elk population estimates into a multiple regression model, the relationship accounted for 75 percent of the variation in EVC (r = 0.866, r^2 = 0.750, P = 0.008, n = 10); partial regression coefficients for AADT (1.43, P = 0.003) and elk population estimates (1.23, P = 0.006) were both significant.

Table 3. Frequency of elk-vehicle collisions (EVC) by SR 260 highway section, Arizona, USA, recorded for the period 2001-2004 by DPS and AFGD, and a comparison of the total EVC to the total EVC in the ADOT database (see table 1) for the same period

	No. of EVC by highway section						Percentage of total
Year	PC	LGV	KR	DC	CC	Total	in ADOT database
2001	10	3	9	1	7	30	96.7
2002	13	0	7	2	18	40	95.2
2003	10	2	7	5	19	43	80.2
2004	14	1	6	4	56	81	51.8
Mean	11.8	1.2	7.3	3.0	25.0	48.5	72.7

Comparison of EVC by highway section and construction classes

The location and frequency of EVC across all SR 260 0.16-km segments were not randomly distributed (Kolmogorov-Smirnov test, d = 0.13, P < 0.005; fig. 3), with EVC ranging from 0 to 3.1/segment/year (mean = 0.15 ±0.02). The mean EVC rate for all SR 260 sections between 1994 and 2004 was 1.1 collisions/km/year (table 4); the PC Section had the highest mean EVC rate of the five sections (1.7/km/year), followed by the CC Section (1.3/km/year). Among sections for all years, we detected significant differences in mean collision rates (ANOVA F = 11.41, df = 4, 50, P <0.001; table 2); the mean collision rate for PC Section was higher than that for the LGV and DC sections (both P <0.001), and the CC section rate was higher than the LGV section (P = 0.009). Considering only before-construction mean EVC rates, we found that they also differed among sections (ANOVA F = 11.31, df = 4, 40, P <0.001). The PC and CC sections had the same mean before-construction EVC rate (0.7 km/year), which were both higher than means for the LGV (0.1/km/year; both P < 0.001) and DC (0.2/km/year; PC Section P = 0.011, CC Section P <0.001) sections. Also, the mean pre-construction EVC rate for the KR section (0.5/km/year) was higher than that for the LGV section (P = 0.012).

In our assessment of EVC by highway construction classes, we found that the mean EVC differed among classes (ANCOVA F = 19.4, df = 2, 51, P <0.001; table 5). The mean before-construction EVC (4.5 collisions/year, n = 45) was lower than that for sections and years during construction (12.4 collisions, n = 7; P = 0.006). Mean after-construction EVC (7.0, n = 3) did not differ from before- (P = 0.631) and during-construction (P = 0.231) classes. When we considered the PC section separately, the only section where construction was completed during our study, we found no differences (P = 0.981) among mean EVC before (7.7, n = 6), during (8.0, n = 2), and after construction was completed (7.0 +1.5, n = 3). On the CC Section, the mean EVC during construction (19.7/year, n = 3) was >2.5x the before-construction mean (7.6/year, n = 8), accounting for the differences among construction classes in our ANCOVA (table 5). In our database, the increase in EVC on the CC Section was particularly dramatic, increasing 3x from 19 in 2003 to 56 in 2004 (table 3) when the highway was opened to traffic before ungulate-proof fencing was properly completed.

Table 4. Number of elk-vehicle collisions by SR 260 highway section, Arizona, USA, 1994-2004, and mean collisions/km/year (±SE) for each section.

	No. of elk-vehicle collisi ons by State Route 260 section					
Year	PC	LGV	KR	DC	CC	Total
1994	4	0	4	4	8	20
1995	4	0	3	2	14	23
1996	10	0	3	2	5	20
1997	8	3	10	2	4	27
1998	8	2	8	3	10	31
1999	12	1	6	4	12	35
2000	6	2	2	0	2	12
2001	10	3	9	1	6	29
2002	10	0	7	2	17	36
2003	6	2	7	5	14	34
2004	5	1	5	3	28	42
Mean collisions/year	7.5	1.3	5.8	2.5	10.9	28.1
Section length (km)	4.6	4.0	5.4	4.5	8.2	26.7
Mean collisions/km/year (±SE)	1.7 (0.18)	0.3 (0.09)	1.1 (0.15)	0.5 (0.10)	1.3 (0.27)	1.1 (0.06)

Comparison of EVC and elk highway crossings

GPS collars were affixed to 33 elk (25 females, 8 males) an average of 412.9 days (±39.1; range = 50-684 days). From these elk, we accrued 101,506 GPS fixes, or 70.1-percent fix success (range = 23.1-100.0), with a mean of 3,075.9 fixes/elk (±378.3; range = 344-7,332). Of these fixes, 46,162 (45.5%) occurred <1 km of SR 260. Collared elk crossed SR 260 3,057 times (fig. 4), with a mean of 92.6 crossings/elk (±23.5); individual elk crossings ranged from 1-691. The mean frequency of highway crossings by cows (112.0 ±29.9) was 3.5x greater than that for bulls (32.1 ±12.1). On average, elk crossed the highway 0.22 times/day (±0.04), with cows (0.28 ±0.05) crossing 4.5x more than bulls.

We rejected the null hypothesis that the frequency distribution of crossings occurred randomly (Kolmogorov-Smirnov test, d = 0.01, P < 0.001); rather, crossings exhibited a strongly clumped pattern (fig. 4). The highest crossing frequency occurred on the PC Section (282.2/km), followed by the CC Section (130.5/km) (table 6). Combined, all other sections exhibited relatively low crossing frequency (<40/km; table 6), though peaks also occurred near meadow-riparian habitats on the KR and DC sections (fig. 4).

Table 5. Dates of construction initiation and completion for SR 260 highway sections, Arizona, USA, and mean number of elk-vehicle collisions (EVC) between 1994-2002 (±SE) by highway construction classes (before, during, and after reconstruction). Letters denote differences among means for the highway construction classes for all highway sections combined and the PC Section separately (ANCOVA).

Highway	Date construction:		Mean EVC (±SE) by construction class and years data (*n*)					
section	Started	Complete	Before		During		After	
PC	2000	11/2001	7.7 (1.3) A	*n* = 6	8.0 (2.0) A	*n* = 2	7.0 (1.5) A	*n* = 3
LGV	-	-	0.3 (0.1)	*n* = 11	-	-	-	-
KR	2002	2005	5.8 (0.1)	*n* = 9	6.0 (1.0)	*n* =2	-	-
DC	-	-	0.6 (0.1)	*n* = 11	-	-	-	-
CC	2001	1/2005	7.6 (1.5)	*n* = 8	19.7 (4.2)	*n* = 3	-	-
All	N/A	N/A	4.5 (0.5) A		12.4 (3.1) B		7.0 (1.5) A, B	

Table 6. Summary of elk crossings, Shannon Diversity Index, and weighted crossings by highway section along SR 260, Arizona, USA, determined from 33 elk fitted with GPS telemetry collars, May 2002-April 2004

Highway section (km)	No. elk crossings (%)	Crossings/ km	Mean SDI [a]	Weighted no. crossings[b] (%)	Weighted crossings/km
PC (4.6)	1,298 (42.4)	282.2	1.00	1,312 (37.1)	285.2
LGV (4.0)	132 (4.3)	33.0	0.65	193 (5.5)	48.2
KR (5.4)	212 (6.9)	39.2	0.75	237 (6.7)	43.9
DC (4.5)	292 (9.5)	64.9	0.70	332 (9.4)	73.8
CC (8.2)	1,070 (35.0)	130.5	1.07	1,451 (41.0)	177.0
All (29.8)	3,057 (100.0)	102.6	0.71	3,534 (100.0)	118.6

[a]Shannon Diversity Index (Shannon and Weaver 1949)
[b]Weighted crossings = $\sum$ (no. of crossings/segment x SDI)

The number of different elk crossing at each highway segment ranged from 0-8, and averaged 3.3. Our weighted crossing frequencies considering SDI for all segments exhibited significant shifts in crossing patterns compared to those without SDI (fig. 4; Kolmogorov-Smirnov test, d = 0.22, P < 0.001). Most apparent were differences for the CC Section, which had high SDI elevated crossings for many segments, some the highest along the entire study area (fig. 4); weighted crossing frequency for the CC Section was 32 percent over the non-weighted crossings (Kolmogorov-Smirnov test, d = 0.28, P < 0.01). At the PC Section, peak crossings shifted from the western portion, skewed by a single cow that crossed there 691 times, to a large peak in the vicinity of the Little Green Valley meadow complex and two wildlife underpasses (fig. 4), which better reflected the high diversity and frequency of elk crossings there. Even with the dramatic shift in crossing peaks for the PC Section, weighted crossing frequency increased only negligibly (1.1%; table 6), and the crossing patterns did not differ. Weighted and raw crossing distributions for the other three sections also did not differ.

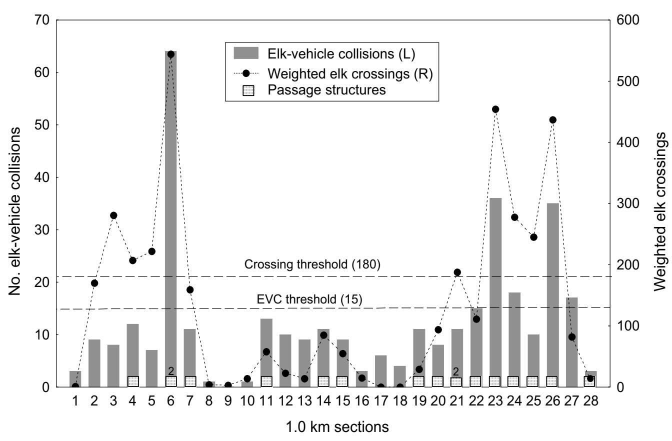

Figure 3. Frequency of EVC reported 1994-2004 and weighted elk crossings determined from 33 elk fitted with GPS telemetry collars from May 2002-April 2004, by 1.0-km sections along SR 260, Arizona, USA. Thresholds for high EVC and crossings are denoted by dashed lines, and passage structures (underpasses and bridges) are denoted within each 1.0-km segment in which they are located.

Spatial relationships between EVC and crossings

The strength of the associations between EVC and elk highway crossings increased as a function of increasing scale (table 7). Our strongest association between EVC and crossings was found at the highway section level for weighted crossings (r = 0.971, r^2 = 0.942, n = 5, P = 0.006), while the weakest occurred at the 0.16-km segment scale for uncorrected crossings (r = 0.396, r^2 = 0.156, n = 200, P < 0.001). The relationships between EVC and weighted elk crossings accounted for an average of 16.2 percent more variation in EVC compared to uncorrected elk crossings (table 7, fig. 5).

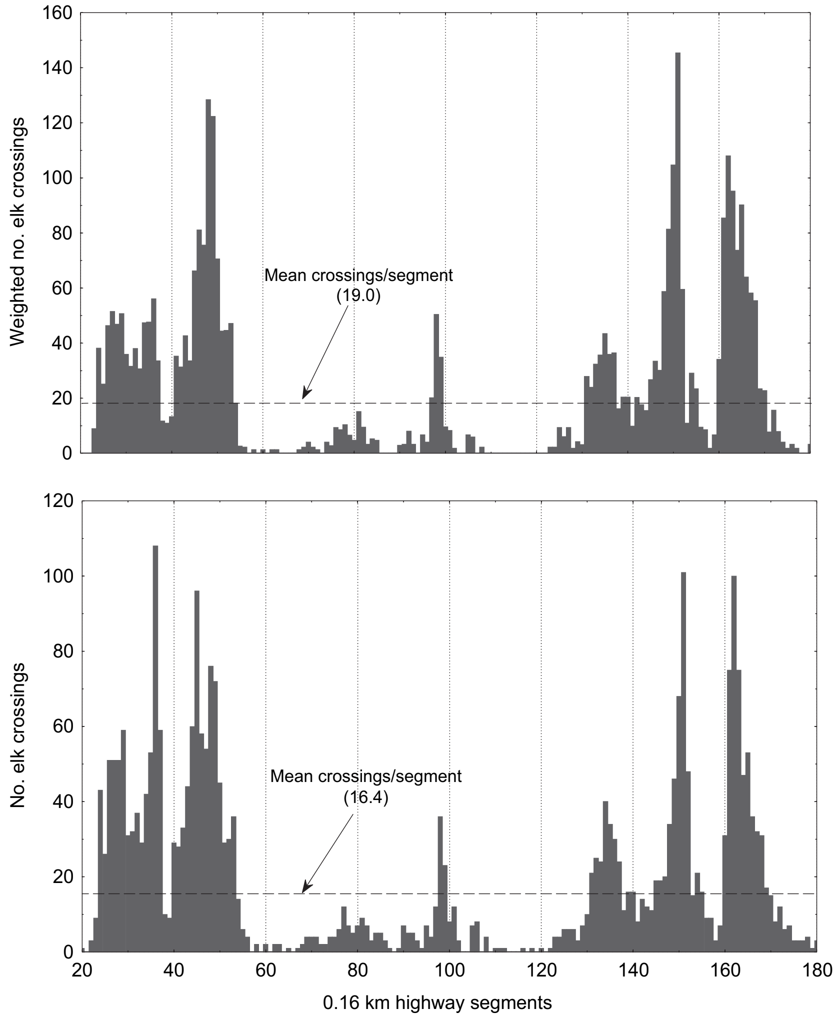

Figure 4. Frequency distribution of elk crossings (bottom) and weighted elk crossings derived from crossings x Shannon diversity index for each segment (top) by 0.16-km segment along SR 260, Arizona, USA, determined from 33 elk equipped with GPS receiver collars, May 2002-April 2004. Highway sections correspond to the following segments: PC (21-50), LGV (51-76), KR (77-111), DC (112-140), and CC (141-200).

Table 7. EVC relationships between highway crossings and weighted crossings by GPS-collared elk at various scales along SR 260, Arizona, USA, including correlation coefficients (r) and coefficients of determination (r^2)

		Elk crossings vs. EVC			Weighted elk crossings[a] vs. EVC		
Scale	n	r	r^2	P	r	r^2	P
0.16 km[b]	208	0.396	0.156	<0.001	0.509	0.259	<0.001
0.50 km	57	0.566	0.320	<0.001	0.700	0.489	<0.001
1.00 km	28	0.688	0.474	<0.001	0.837	0.701	<0.001
1.62 km	18	0.715	0.512	<0.001	0.833	0.693	<0.001
Section[c]	5	0.901	0.812	0.037	0.971	0.942	0.006

[a]Weighted elk crossings = Σ (no. of elk crossings/segment x SDI)
[b]Corresponds to 0.10 mi segments
[c]Average length of each highway section = 6.0 km

The associations between EVC and weighted elk crossings at the 1.62-km and 1.0-km scales were comparable, with both explaining 70 percent of the variation in EVC (table 7, fig. 5). However, the strength of the relationships diminished at scales below 1.0 km; variation explained declined incrementally by >20 percent between each scale below the 1.0-km level (fig. 5).

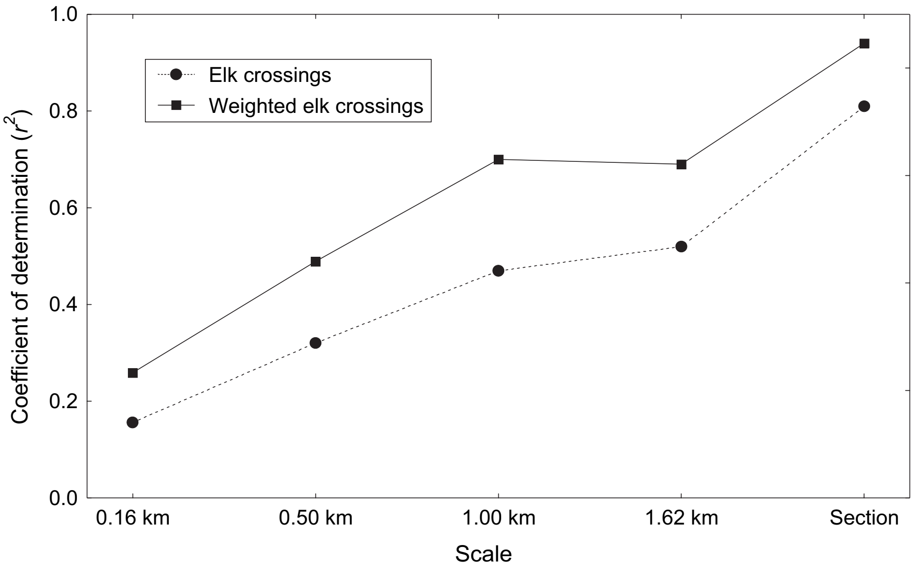

Figure 5. Coefficients of determination (r^2) for linear regression comparisons of EVC to elk crossings and weighted crossings conducted at various scales along SR 260, Arizona, USA. EVC occurred 1994-2004, and elk crossings were determined from 33 elk fitted with GPS telemetry collars between May 2002 and April 2004.

At the highway section scale, the number of 0.16-km segments located within 0.25 km of riparian-meadow habitat was strongly associated with EVC (r = 0.981, r^2 = 0.962, n = 5, P = 0.003). The number of segments located in proximity to riparian-meadow habitat on each section also was related to the frequency of weighted elk crossings (r = 0.898, r^2 = 0.806, n = 5, P < 0.038). At the 1.0 km scale, the number of segments in proximity to riparian-meadow habitat was associated with both the frequency of EVC (r = 0.751, r^2 = 0.564, n = 28, P < 0.001) and weighted elk crossings (r = 0.772, r^2 = 0.596, n = 28, P < 0.001).

Temporal relationships between EVC and crossings

We detected monthly and seasonal differences in the frequency of both EVC and highway crossings. Observed mean monthly EVC for all elk differed from expected (X^2 = 34.0, df = 11, P < 0.001), as did crossing frequencies for all elk (X^2 = 220.8, df = 11, P < 0.001; fig. 6). EVC that occurred during September-November accounted for 49 percent of all collisions (fig. 6); most collisions with cows occurred in November (15%), while October accounted for the highest proportion of bull collisions (28%) and all collisions (20%). While observed monthly EVC (P = 0.251) and crossings (P = 0.691) did not differ from expected for cows, those involving bulls differed from expected (ECV X^2 = 122.0, df = 11, P < 0.001; crossing X^2 = 114.6, df = 11, P < 0.001; fig. 7); cow EVC and crossings were relatively consistent throughout the year. During November-April, only 18 crossings (7% of total) and 3 EVC (12%) involving bulls were recorded, with a subsequent increase from May-October (fig. 7). The proportion of elk crossings by month (as an expected proportion for EVC) differed from the actual observed proportion of EVC (X^2 = 24.8, df = 11, P = 0.010), and differed for both cows and bulls. In contrast to elk, the monthly frequency of recorded deer collisions (n = 70) did not differ from expected, though half the collisions involving deer occurred from November-February.

On an annual basis, the ratio of bull:cow EVC (23.6:100) was less than half the mean bull:cow ratio (51.8:100) from annual surveys (2001-2004) conducted in GMU 22 and 23, and the surveyed ratio (expected) differed from the collision ratio (observed; X^2 = 101.9, df = 3, P < 0.001). However, considering only the period June-October which accounted for 85.7 percent of bull crossings and 84.0 percent of EVC involving bulls, the bull:cow EVC ratio (48.8:100) did not differ from the surveyed population bull:cow ratio (P = 0.808).

Recorded EVC by day differed from expected (X^2 = 22.0, df = 6, P < 0.001), while elk crossings by day (range = 318-384/day) did not differ from expected (P = 0.169) unless we applied daily AADT factors to the expected crossings (X^2 = 34.8, df = 6, P < 0.001). However, the proportion of elk crossings by day (expected) did not differ from the proportion of EVC (P = 0.424), even with daily AADT factors (P = 0.520). The greatest departures in daily EVC above expected levels occurred on Monday (35% above expected) and Friday (19%), and the greatest departure below expected occurred on Wednesday (73% below expected; fig. 8). In applying AADT daily factors to adjust for differential daily AADT, the number of EVC on Monday remained the highest of the week, while Friday dropped 17 percent to below expected levels, and EVC on Sunday increased 12 percent (fig. 8). Observed deer collisions did not differ by day unless AADT daily factors were applied (X^2 = 13.4, df = 6, P = 0.038), which resulted in the same daily trends as EVC.

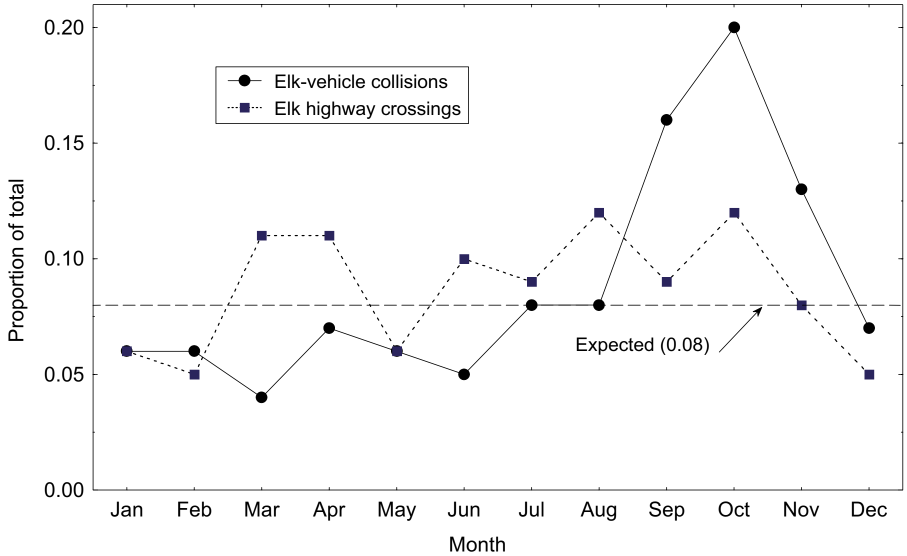

Figure 6. Proportions of EVC (solid line) and elk highway crossings (dashed line) for all elk by month along State Route 260, Arizona, USA. EVC occurred between 1994-2004, and elk crossings were determined from 33 elk fitted with GPS telemetry collars between May 2002 and April 2004. Both observed EVC (?2 = 34.0, df = 11, P < 0.001) and elk crossings (?2 = 220.8, df = 11, P < 0.001) differed from expected values.

Both the observed frequency of EVC and elk highway crossings by two-hour time interval differed from expected (X^2 = 271.0 and 672.2, respectively; both df = 11, $P < 0.001$). Also, the proportion of elk crossings that occurred in each time interval (expected) differed from the proportion of EVC (X^2 = 39.4, df = 11, $P < 0.001$). The largest proportion of EVC (31%) occurred between 19:00 and 21:00, with nearly 60 percent of collisions reported between 17:00 and 11:00 (fig. 9). The largest proportion of elk crossings occurred between 5:00 and 7:00 (18%); 83 percent of crossings were made at nighttime between 19:00 and 7:00 (fig. 9). A higher proportion of EVC (59%) occurred relative to crossings (33%) in the evening hours (17:00-23:00), while a lower proportion (19%) occurred during morning hours (3:00-9:00) relative to crossings (34%). We found that 34 percent of EVC occurred within a one-hour absolute departure from sunrise or sunset, and 55.5 percent occurred within a two-hour departure period (fig. 10). Similarly, 35 percent of deer collisions occurred within a one-hour departure, and 50 percent, within two hours of sunrise or sunset (fig. 10).

Determination of high EVC and crossing sections

Our calculations defined high EVC incidence sections as those with >15 EVC from 1994-2004 (mean = 12.3), and high crossing sections as those with >180 weighted crossings (mean = 135.1). All six of the identified high EVC sections (of 28 total) will have a bridged passage structure (underpass or bridge) in place when highway reconstruction is complete, and passage structures will occur on seven of the nine identified high crossing sections (fig. 3). Combined, high EVC and crossing sections accounted for 11 different sections, of which 9 (81.8%) will have a passage structure in place upon highway reconstruction (fig. 3).

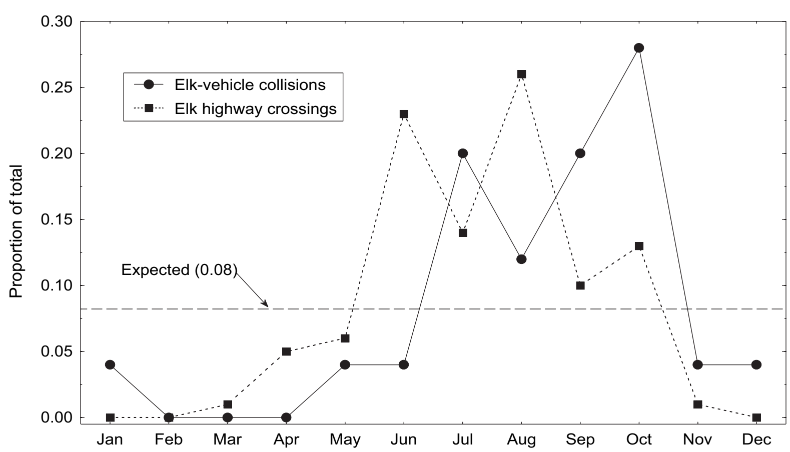

Figure 7. Proportions of EVC and elk highway crossings for bull elk by month along State Route 260, Arizona, USA. EVC occurred between 1994-2004, and elk crossings were determined from 8 bulls fitted with GPS telemetry collars between May 2002 and April 2004. Both observed EVC (?2 = 122.0, df = 11, P < 0.001) and elk crossings (?2 = 114.6, df = 11, P < 0.001) differed from expected values.

Discussion

The estimated proportion of wildlife killed by vehicles and recorded in WVC databases has ranged from 17 percent for deer (Forman et al. 2003), 25-35 percent for all wildlife species (Sielecki 2004), 50 percent for deer (Romin and Bissonette 1996b), to 80 percent for moose (*Alces alces:* Garrett and Conway 1999). The long-term ADOT database we used for our analyses included nearly 75 percent of all WVC that were documented along SR 260 during 2001-2004. Though smaller and causing less property damage than elk, 68 percent of deer collisions were nonetheless recorded in both databases. From 2001-2003, 88 percent of EVC were documented in both databases, but dropped in 2004 when we documented 10 calf EVC collisions not reported in the ADOT database.

EVC relationships to AADT and elk population estimates

We found that AADT and estimated elk population levels jointly influenced annual EVC along SR 260; based on partial regression coefficients, AADT had a stronger influence on EVC, as reported by Seiler (2004). Traffic volume has frequently been reported as a factor contributing to WVC for a wide range of wildlife (Inbar and Mayer 1999, Joyce and Mahoney 2001, Forman et al. 2003). Other studies have linked traffic volume and relative animal abundance to the incidence of WVC (Fahrig et al. 1995, Romin and Bisonnette 1996, Philcox 1999, Seiler 2004), including Gunson and Clevenger (2003) for elk in Alberta. In contrast to our study, Gunson and Clevenger (2003) found that mean EVC declined as traffic volume increased (r^2 = 0.82), though they believed that a decline in their elk population influenced this relationship. They also reported a positive relationship between elk abundance and EVC (r^2 = 0.75) independent of traffic volume.

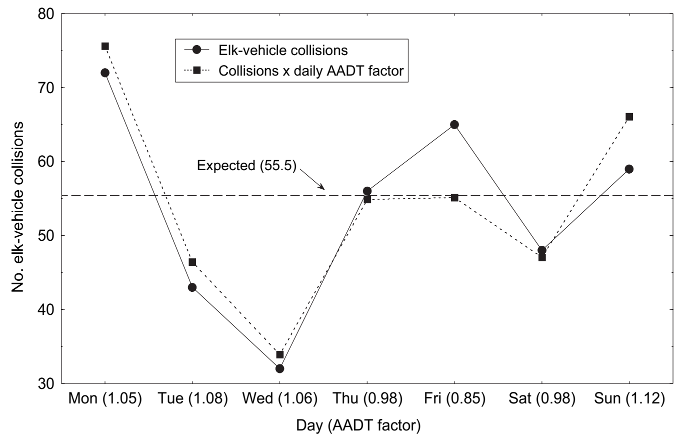

Figure 8. EVC frequency by day and EVC corrected with daily AADT factors accounting for differential traffic volume by day. Both observed EVC (X^2 = 22.0, df = 6, P < 0.001) and AADT-corrected EVC (X^2 = 20.7, df = 6, P < 0.001) differed from expected values. EVC occurred along SR 260, Arizona, USA, 1994-2004.

Using the mean annual increase in AADT of 17.8 percent/year (1994-2003; table 1), and holding the elk population constant at 2003 levels, our multiple regression model predicted that EVC would double from 34 in 2003 to 73 in 2006 without measures to reduce WVC. The potential increase in EVC could be far greater given a higher annual AADT rate of increase (e.g., 38% from 2002-2003) reflective of Arizona's current human population growth patterns, and justifies the extensive and costly measures to reduce the incidence of WCV on SR 260.

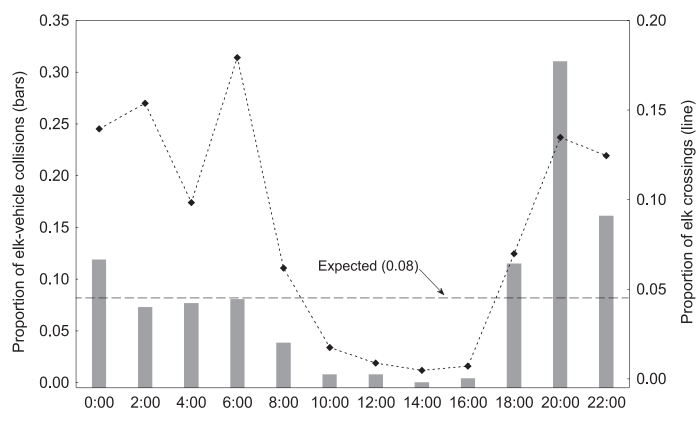

Figure 9. Proportions of EVC (bars) and elk highway crossings (dashed line) by 2-hour time interval along State Route 260, Arizona, USA. EVC occurred between 1994-2004, and elk crossings were determined from 33 elk fitted with GPS telemetry collars between May 2002 and April 2004. Both observed EVC (X^2 = 271.0, df = 11, P < 0.001) and elk crossings (X^2 = 672.2, df = 11, P < 0.001) differed from expected values.

Comparison of EVC by highway section and construction classes

Our mean EVC rate for all highway sections (1.1/km/year) exceeded those reported for Alberta (Gunson and Clevenger 2003) and British Columbia (Sielecki 2004), but was lower than the rate (1.6/km/year) reported by Biggs et al. (2004) in New Mexico. The comparative EVC rates for SR 260 validated the prioritization for reconstruction (Route 260-Payson to Heber EIS, ADOT Environmental Planning Section, Phoenix, AZ); PC Section 1st (1.7/km), CC Section 2nd (1.3/km), and KR Section 3rd (1.1/km). The two sections where reconstruction has not begun (LGV and DC) had a combined EVC rate of 0.4/km/year.

Hardy et al. (2003) stressed the value of conducting "before-after, control-impact" (BACI; Underwood 1994) assessments to determine the effects of highway construction and efficacy of measures to reduce WVC and promote permeability. Phasing of SR 260 construction among sections, presence of control sections, and the long-term ADOT database provided the opportunity to conduct such an assessment. To date, the PC Section was the only section where we compared after-construction EVC to those before and during highway construction; we will soon be able to make similar comparisons for the CC and KR sections.

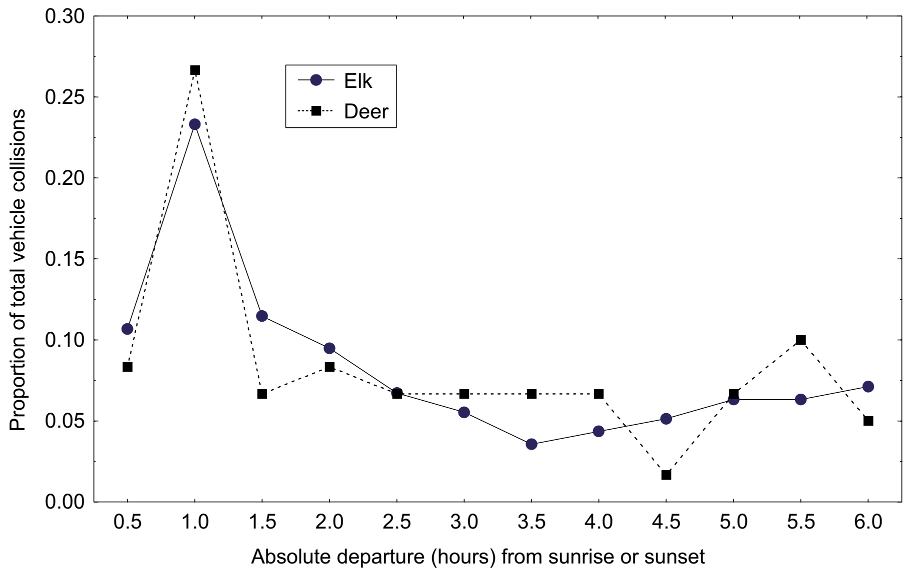

Figure 10. Absolute departure (by 0.5 hour increments) from sunrise or sunset for vehicle collisions with elk (solid line) and deer (dashed line) along SR 260, Arizona, USA, for collisions that occurred 1994-2004.

EVC frequency on the PC Section remained largely unchanged across all construction phases. Yet, given the 67-percent increase in mean AADT from before-construction levels (3,754.8 vehicles/day ±272.4) to an after-construction mean of 6,267 vehicles/day (±1,094.0), the two wildlife underpasses with limited ungulate-proof fencing and the bridge over Preacher Canyon have yielded benefit in maintaining EVC in spite of increased traffic levels. These measures have promoted elk permeability across SR 260, with 40 percent of weighted elk crossings for the PC Section having occurred below grade at the three passage structures, even with limited fencing.

The large increase in EVC on the CC Section during construction between 2003 and 2004 reflected opening of the highway to traffic before ungulate-proof fencing was completed, along with increased AADT and vehicular speed (Forman et al. 2003). While fence paralleling the highway was erected in spring 2004, fencing through the seven passage structures was not erected so as to tie them together prior to opening of all lanes to traffic. Elk continued to cross at grade or accessed the median of the divided highway, contributing to the rash of EVC. In the five months between when the CC Section was opened to traffic and the fencing completed (December 2004), we documented 38 EVC here. In the 10 months since fence completion along 57% of the CC Section, 8 EVC have been documented; 6 occurred along unfenced sections of the highway. We anticipate that a dramatic reduction in EVC will occur with the completion of fencing. Fencing's utility in reducing WVC is well accepted, especially in conjunction with effective passage structures (Ward 1982, Foster and Humphrey 1995, Clevenger et al. 2001), though Ward (1982) documented an increase in WVC in the first year after fencing was erected.

Comparison of EVC and elk highway crossings

GPS telemetry afforded us an unprecedented spatial and temporal assessment of elk highway crossing patterns and permeability (Dodd et al. *In review*), and allowed us to compare crossing patterns to EVC. With mean GPS fix accuracy to within ±12 m, and with >85 percent of our fixes within 20 m of known validation locations (Dodd et al. *In review*), GPS telemetry constituted a sufficiently accurate tool to assess elk crossing patterns and address our study objectives.

Spatial relationships
Several studies have demonstrated that WVC do not occur randomly, either spatially or temporally (Puglisi 1974, Bashore et al. 1985, Clevenger et al. 2001), including EVC (Gunson and Clevenger 2003, Biggs et al. 2004). Both our EVC and elk crossings patterns differed from a random distribution. Many spatial factors contribute to distribution of WVC (Farrell et al. 2002), including topography, wildlife concentrations and density (Hubbard et al. 2000), and highway proximity to preferred (Farrell et al. 2002) and seasonal (Romin and Bissonette 1996*b*, Gordon and Anderson 2003) habitats.

Though intuitive, we confirmed the relationship between the frequency of elk highway crossings (and weighted elk crossings) and EVC. The fact that weighted elk crossings accounted for more variation in the relationship points to the joint influence of crossing frequency, number of crossing elk, and the evenness in crossing patterns. Dodd et al. (*In review*) found that individual variation in crossing rates also influenced the likelihood of elk being involved in EVC; of the four collared elk killed in EVC, they represented 57 percent (n = 7) of those with >0.40 crossings/day, while no elk with <0.20 crossings/day (n = 18) or 0.20-0.40 crossings/day (n = 7) were killed in EVC.

Though our strongest relationship between weighted crossings and EVC was found at the highway-section scale, this scale provides limited management utility. The 1.0-km scale was optimal as it afforded relatively high "power" (r^2 > 0.7) and was refined enough to determine WVC and crossing patterns and plan mitigation measures to address WVC and permeability. At this scale, 9 of 11 (82%) high EVC or crossing segments have passage structures planned or implemented. The relationship between crossings and EVC points to the utility of using collision and road kill data as a surrogate measure of weighted crossings determined by costly GPS assessment.

The relatively weak relationship (r^2 < 0.3) between EVC and weighted crossings at the 0.16-km scale probably reflected inaccuracy in both GPS elk crossing segment determination and WVC reporting error, as found by Gunson and Clevenger (2003; mean reporting error >0.2 km).

Temporal relationships
We recorded a dramatic increase in the proportion of EVC occurring in fall (September-November); this increase greatly exceeded the proportion of highway crossings by all elk, though crossings also exceeded the expected proportions at this time (fig. 6). For bulls, an even greater spike in EVC occurred from July-October, with peaks in July and October (fig. 7). Gunson and Clevenger (2003) reported an increase in EVC in fall attributable to increased elk numbers from calf recruitment, and Biggs et al. (2004) reported increased EVC in fall and winter, with EVC in winter associated with snows and migrating elk. With deer, Romin and Bissonette (1996b), Hubbard et al. (2000), and Puglisi et al. (1974) attributed increased collisions in fall to breeding and sport hunting.

In our case, the seasonal increase in EVC probably reflected a combination of factors. First, the fall increase in EVC reflected an influx of migratory elk that moved from summer range atop the Mogollon Rim beginning in October (Brown 1990, 1994*b*); these elk were not represented in our GPS crossing data, possibly accounting for the lack of a comparable increase in crossings by all elk in fall (fig. 6). This increase in overall elk numbers, in addition to calf recruitment (Gunson and Clevenger 2003) probably accounted for the fall peak in EVC. Further, the onset of the breeding season in September and October coincided with peaks in the proportion of EVC for bulls and all elk combined, both with the highest proportion of EVC in October (fig. 6 and 7).

The influence of riparian-meadow habitats is reflected in seasonal fluctuations in EVC and elk crossing patterns. Most apparent were the strong associations between EVC and crossings to the proximity to riparian-meadow habitats. The original alignment of SR 260 abutting several streams and large meadow areas (fig. 1) has contributed to long-term wildlife-vehicle conflicts. Elk use of riparian and meadow habitats for foraging and watering, particularly during prevailing drought conditions, appeared to be a large determinant of where EVC and elk crossings occurred. Further, riparian areas and drainages are preferred travel lanes and corridors for elk (Skovlin 1982, Servheen et al. 2003).

We believe that the high proportion of bull EVC and crossings during late-spring and early-summer were tied to nutritional demands associated with antler growth (Bubenik 1982). Riparian-meadow habitats provide forage of highest nutritional quality, earlier in the growing season than adjacent forest habitats (Nelson and Leege 1982), and higher quality diets permit increased digestive rates and rumen turnover, allowing elk to feed more frequently (Green and Bear 1990). Increased movement of bulls to riparian-meadow habitats adjacent to SR 260 to feed probably influenced EVC and crossing patterns. While only four percent of the area within 1 km of SR 260 comprised riparian-meadow habitats, 20 percent of all bull GPS fixes occurred in such habitats, including 46 percent of the fixes in August (Dodd et al. *In review*). Cow elk also have high nutritional demands during lactation through the summer and fall (Nelson and Leege 1982); 38 percent of EVC involving cows occurred during September-November. As with bulls, we believe that cows best met their high nutritional demands by foraging in riparian-meadow habitats adjacent to SR 260, which contributed to EVC at this time.

Gunson and Clevenger (2003) reported greater numbers of female EVC, though the sex ratio of EVC was actually skewed toward bulls given their low bull:cow ratio. Romin and Bissonette (1996*b*) reported bias toward male deer in WVC, as did Joyce and Mahoney (2001) for moose. Relying on the year-long mean EVC sex ratio for SR 260 would lead us to conclude that EVC disproportionately affect the female segment of the elk population relative to the surveyed ratio.

However, in applying our GPS crossing data to address the EVC sex ratio only during the period when bulls crossed SR 260, EVC occurred in proportion to the ratio of the surveyed population.

Gunson and Clevenger (2003) reported more EVC on weekend days (Friday-Sunday) versus weekdays, attributable to high recreational and tourist traffic. Though SR 260 was subject to a similar traffic volume pattern, with highest volume on Friday and Saturday, the highest incidence of EVC occurred on Monday. On Friday, the daily AADT-adjusted EVC was below expected in spite of the highest traffic volume, suggesting that elk responded to the 25 percent traffic volume increase between Wednesday (lowest EVC incidence) and Friday. The incidence of Sunday EVC exceeded the expected level of accidents especially when adjusted by daily AADT factors, and by Monday (23% below Friday traffic volume) EVC incidence far exceeded the expected level. Thus, EVC (and AADT daily factor-adjusted crossings) appeared to reflect a behavioral response to avoiding high traffic volume on Friday and Saturday, followed by elevated EVC on Sunday and Monday despite lower traffic volume. Mueller and Berthoud (1997) hypothesized that highways with AADT levels between 4,000 and 10,000 present a strong barrier that would repel animals; above 10,000 vehicles/day, highways would become impermeable to most species. Brody and Pelton (1989) reported a negative relationship between black bear crossings and traffic volume, as did Waller and Servheen (2005) for grizzly bears (*U. arctos*). Our Friday and Saturday AADT levels often exceed 10,000 AADT, leading to lower than expected EVC and crossings reflective of behavioral adaptation by elk. Surges in EVC and crossings on Sunday and Monday probably reflected increased movements by elk following peak AADT days. Video camera surveillance of two wildlife underpasses on the PC Section found a similar pattern where elk use was below expected levels on Friday and Saturday and exceeded expected on Sunday and Monday, attributable to differential daily traffic volume (Dodd et al. *In review*).

Haikonen and Summala (2001) reported that a large peak in WVC, 46 percent of moose and 37 percent of whitetail deer collisions, occurred within three hours after sunset tied to circadian rhythms associated with light. We found an even more dramatic peak in WVC after sunset; 67 percent of EVC and 64 percent of deer collisions occurred within a three-hour departure of sunset. Gunson and Clevenger (2003) and Biggs et al. (2004) noted similar evening peaks in EVC, though the latter also noted a secondary peak in the morning tied to increased commuter traffic volume. Our morning EVC remained below expected levels though a third of elk crossings occurred between 3:00-9:00; SR 260 does not exhibit morning traffic as reported by Biggs et al. (2004). Green and Bear (1990) found that 38-60 percent of daily elk feeding activities occurred at dawn and dusk throughout the year, with the highest proportion of feeding at these times in the fall-winter when Gunson and Clevenger (2003), and Biggs et al. (2004), and we noted peak EVC.

Management Implications

Our comparison of EVC and highway crossings points to the high similarity in spatial patterns, and to a lesser degree temporal patterns, exhibited by elk along SR 260 assessed by the two methods. These similarities point to the utility and validity of using EVC data as a surrogate measure of weighted crossings determined by costly GPS assessment. It also underscores the value of WVC data in developing strategies to maintain permeability and increase highway safety (Romin and Bissonette 1996*a*, Farrell et al. 2002) by selecting the best locations of passage structures (Clevenger et al. 2002, Barnum 2003). Consistent tracking of WVC provides a means to assess the impact of highway construction on wildlife and to evaluate the effectiveness of measures to reduce WVC and promote permeability. We found that aggregating EVC patterns to 1.0-km segments proved to be a scale that optimized the strength of the relationship between EVC and elk highway crossings and management utility.

Our temporal EVC and crossing patterns reflect the influence of riparian-meadow habitats on elk movements and the conflict created between elk and vehicles with the original alignment of SR 260 adjacent to such habitats. Yet given this conflict, most SR 260 wildlife underpasses have been planned or constructed near riparian-meadow areas, which will contribute to their acceptance and use by elk and other wildlife (Clevenger and Waltho 2003, Servheen et al. 2003). Where fencing is erected to block crossings and funnel animals to underpasses (Clevenger et al. 2001), the attractive nature of riparian-meadow habitats will expedite learning by elk in their use of underpasses (Clevenger and Waltho 2003).

Gaining an understanding of EVC patterns and identifying relative collision potential associated with season, day, time, and relationships to traffic volume will provide highway planners insights to develop strategies to educate motorists of WVC risks as an important aspect of reducing collisions, human injuries, loss of life, and property damage.

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